U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE

Slope Stability Hazard Assessment of Hatchery Fire Complex Wenatchee National Forest

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PART 1

Executive Summary

Part 1 is a short description of the project. Readers using Part 1 in conjunction with the three plates from the back cover jacket will have a summary of this project for understanding the work and for management to make preliminary decisions. Part 2 gives detailed descriptions of how the work was completed from field work to analyis to possible mitigation development.

Problem Definition

The Hatchery Fire Complex is located in Chelan County, Washington (see Figure 1 on page 2). Purpose of this project was to identify and evaluate existing and potential sources of slope movement within the Hatchery Fire Complex, specifically within the Tumwater Canyon, lower Icicle Creek valley, and Wedge Mountain areas. This project falls within a scoping level as required by federal legislation (e.g., National Environmental Policy Act, 1969; and National Forest Management Act, 1976); therefore, information within this report is accurate for planning purposes only. Data from this report will be used in formulating an action plan in early 1995 for management decisions. Various alternatives are developed in an action plan and each address the predicted short- and long-term effects that may result from each alternative.

The hazard assessments were made in the context that hazards are natural geologic conditions that have a potential for slope movement (bedrock and soil). In this type of geologic analysis the associated risks from hazards are usually addressed in the framework that hazards are risks to resources (e.g., wildlife habitats, roads, and structures) that have the potential of being affected by the hazards (Koler, 1994). The hazard/risk assessment for this project area became important because many interagency resource specialists made the observation that several areas of potential rockfall and debris flow sites (hazards) were within areas of high intensity wildfire upslope from roads and structures (resources having probability or risk of degradation or loss). This was an important observation because within much of the scientific literature there is a clear relationship between vegetation root strength and slope stability (e.g., O'Loughlin, 1974; O'Loughlin and Ziemer, 1982; Sidle, 1980; Swanston, 1974; Ziemer, 1981; Ziemer and Swanston, 1977). Therefore a potential cause/effect relationship was assumed by these resource specialists for a loss of tree root strength (from fire-caused mortality) and an increase in slope instability.

Fire usually will increase the timing but not the magnitude for rockfall. However, fire will increase the debris flow magnitude and frequency. Modelling in this project was for post-fire conditions. In this study the probabilities determined for rockfall were less than 10%. Although this seems to be a low probability for post-fire rockfall, the location of structures and roadways that may be at risk made it important to assign relative hazard ratings.

Due to the constraints of this project including the aerial extent (10 square miles), elevation (a total of 100,000 vertical feet accessed over 48 transects), time (4 weeks of field work), and weather (potential snowfall), only those areas of high and moderate burn intensity close to major transportation routes, structures, and homes were evaluated. The following summaries for the three project areas give the current situation and list some potential recommendations for mitigation.

Tumwater Canyon

Current Situation

Rockfall

In general, little or no material will fail and travel far downslope from the mid-slopes or ridge top in areas surveyed. Using field data and modeling, in our analysis we evaluated rockfall by two sizes: average size and maximum size. Except for area T-4, none of the average size materials have the potential to reach State Route 2 (S.R. 2) or any structures. Average size rocks (2 ft in diameter) in the T-4 area have a 3.5% probability of reaching S.R. 2 . Some areas have possible maximum size boulders reaching S.R. 2 or structures. These include T-3 (8 ft boulders with 1.5% probability), T-4 (3 ft boulders with 10% probability), T-6 (4 ft boulders with 5.6% probability), T-10 (3 ft boulders with 4.4 % probability), T-11 (3 ft boulders with 3.3% probabilty), T-12 (2 ft boulders with 0.1% probability), and T-13 (2 ft boulders with 2.4% probability). Also a large boulder (12 ft) in the T-6 area could be initiated from a rock outcrop, but we did not include this in the maximum-size rockfall analysis. This boulder was analyzed separately for reaching S.R. 2 or structures. If the boulder breaks up into smaller diameter boulders (4 ft or less) as it travels downslope, then most of the material will not reach S.R. 2. However, if this boulder retains its size it has a greater chance of reaching S.R. 2 after failure and may become a concern.

Hazard ratings were assigned by 3 factors: 1) large rock source volume for rockfall failure; 2) kinetic energy > 50,000 ft-lbs (rockfall boulder energy); and 3) rockfall having a probability greater than 4% reaching S.R. 2 or structures. High ratings had 3, medium ratings had 2, and low ratings had < 2 factors. One area, T-6, had a hazard rating adjusted up from medium to high because it has a relatively larger maximum boulder size (4 ft) compared to most other areas, and there are several structures that some large boulders may reach (5.6% probability). Hazard ratings displayed in Plate 1 are only for maximum-size boulders because no average-size boulders, except for area T-4, reached areas of concern. High hazard ratings were assigned to areas T-6, T-10, and T-11. Medium hazard ratings were assigned to areas T-3 and T-4. Low hazard ratings were assigned to T-1, T-12, and T-13. For a complete listing of hazard ratings for both average and maximum-size boulders, see Table 8 on page 29 in Part 2.

Debris Flows

The evaluation of debris flows for this project included the historical interpretation of slope movement for the last 45 years using available aerial photographs. This work was followed by field interpretations, and modeling.

Debris flow activities that have occurred over the last 45 years have probably been associated with heavy rainfall or snow avalanche activities. In most cases the debris flow materials did not reach the Wenatchee River but were deposited on upper slopes in depositional areas. The one exception is the debris flow within Falls Creek that ranout to the Wenatchee River, probably associated with the November, 1990, storm and flooding. Numerous small-scale features were located on midslopes within or adjacent to area T-1. These features are probably related to rain or snow storm activity in 1986 and did not travel the full slope length. The most recent movement prior to the wildfire appears to have occurred during the November, 1990, storm. The most recent post-fire activity occurred during heavy rainfall from October 31 through November 1, 1994, when material failed in area T-11 and was deposited on S.R.2.

An early concern in this project was the question about temporary damming of the Wenatchee River. In the recent geologic past (several thousand years before the present) there has been enough material moving downslope to be deposited within the Wenatchee River. Also, Tumwater Canyon has a recent history of snow avalanching as documented in Washington State Department of Transportation (WSDOT) documents. If material is deposited in the Wenatchee River, some temporary impoundment of water may occur behind a dam. In a worse case the dam will be a few feet high (less than 10 feet

based on estimates from field data) and water will remain impounded for approximately a few minutes until the dam fails. Correspondence with Robert Schuster, U.S. Geological Survey, indicates that for any significant natural dam hazard to occur, the dam height must be at least 20 to 30 feet high. This case is unlikely, even in the worse case given above. Therefore, temporary damming of the Wenatchee River by debris flows will probably not occur.

Ten of the nineteen debris flow events, located in the aerial photography work, are on the west-facing slopes (see Plate 3). Debris flows on the east-facing slopes, unlike those on the west-facing slopes, have long runouts. The cause of this difference is probably that the east-facing slopes are higher, and longer than the west-facing slopes.

Hazard ratings for debris flows were assigned using the following factors: 1) estimated runout length of a large magnitude event, 2) elements at risk in the path of the potential runout, 3) probability of failure based on the slope modeling, and 4) site factors mitigating the delivery potential. High hazard areas are those with a high post-fire probability of failure with potential to impact structures. Areas T-3, T-6, T-7, T-11, and T-13 were assigned high hazard ratings. Medium hazards were assigned to areas based on two different groupings: 1) those with low probabilities but with elements at risk, and 2) those with moderate or high failure probabilities with site factors mitigating delivery. Areas T-1, T-4, T-5, and T-12 were assigned medium hazard ratings. Low hazards were assigned for areas with low probabilities of post-fire failure and those where maximum estimated runout zones did not include any elements of risk. Areas T-2, T-8, and T-10 were assigned low hazard ratings.

Snow Avalanche

A 1975 WSDOT summary of snow avalanche activity in Tumwater Canyon states that the majority of snow avalanches on the east or highway side of the canyon initiate within the lower 500 feet of the slope. These small to medium-size slides occur quite frequently and are accompanied by rock and soil. The study would also suggest that perhaps some of the apparent historic debris flow activity on the west slopes of the canyon are associated with snow avalanches. Known snow avalanches that have reached and crossed the Wenatchee River have initiated in the Drury Creek drainage on the east side of the canyon. Therefore, future temporary damming by snow avalanches will probably occur. These temporary dams, however, will probably last only a few minutes; therefore, down stream flooding will probably be insignificant.

Recommendations

Rockfall

A "no action mitigation alternative" may be acceptable because little material will reach S.R. 2 or structures. The location of the buildings in the potential rockfall deposition zone, however, may make the "no action mitigation alternative" unacceptable, and therefore some other alternative may be chosen by management (see rockfall discussion for more information). If this alternative is unacceptable for management, then a cost-effective alternative could be the placement of an earth or gravel berm at the toes of the depositional zones. This alternative can also be utilized for mitigating debris flows (see summary below). Another alternative, probably the most costly, is the installation of rockfall fences, but it is unlikely that it is the most cost-efficient method for handling both rockfall and debris flows.

Debris Flows

Possible mitigation for debris flows may also be included for rockfall. Areas T-6 and T-11 were assigned high hazard ratings for both rockfall and debris flow activities. As mentioned above, the placement of a berm may be an acceptable alternative for both of these processes. During placement of these berms it may be feasible to also excavate large collection "sinks" to collect both rock and debris behind the berms. Areas T-3, T-7, and T-13 were also assigned high ratings for debris flow and the placement of berms and/or "sinks" may also be suitable mitigation. In areas where the depositional zone is large and has very gentle slopes (12 ° or less), a possible mitigation alternative may include the retainment of standing timber. Another alternative for these high hazard areas is to develop an early warning system tied to high rainfall during especially wet winters and springs. In this alternative, if a rainfall event reaches a certain threshold an emergency action plan is implemented.

Snow Avalanches

In the 1975 WSDOT Avalanche Atlas, 34 avalanche tracks were located on the east side of Tumwater Canyon. In this document, the importance of vegetation was given as the primary reason for avalanche initiation being limited to steep, narrow channels. Now that vegetation has been removed because of fire mortality, it is logical that snow avalanche initiation sites will no longer be limited to these high gradient channels. The obvious alternative for mitigation is to get live trees established on

these slopes as quickly as possible. In the meantime, if dead trees are to be harvested, stump height should be higher than normal to lend stability to the snowpack on these slopes.

Summary

Areas T-3, T-6, T-7, T-10, T-11, and T-13 have been assigned high hazard ratings for either rockfall, debris flows, or both processes. In all cases it is important to reestablish live trees within these areas to help retain rock, soil, and snow on the slopes. Probably the most viable mitigation alternative is to excavate collection "sinks" and place berms on toes of depositional zones for both rockfall and debris flows.

Lower Icicle Creek Valley

Current Situation

Rockfall

The numerous rock talus deposits along the lower slopes and floor of the Icicle Creek Canyon, indicate rockfall has been a frequent slope process in the recent geologic past, and continues today with some frequency as indicated by interviews with residents. Some large boulders have also been located within a developed aggregate pit source near the fish hatchery indicating that rockfall was probably active in the recent geologic past (thousands of years). The factors used in assigning ratings were: 1) location of homes in runout areas; 2) probability > 5%; and 3) average kinetic energy > 20,000 ft-lbs. In the twelve areas evaluated for average-size boulders, no boulders reached areas of concern. Analysis using maximum size boulders had only three areas (R-2, R-11a, and R-11b) giving results with three factors for a high hazard rating. Two areas (R-12 and R-13) had results with two factors for a medium rating; one (R-1) was given a low to medium rating with two factors or less; and, the rest were assigned low ratings with one factor or less. The two areas assigned medium ratings had no homes at risk, but both had potentially large kinetic engergies and short runout distances. The one low-to-medium rating was assigned to an area that has several homes and a road below it. This area (R-1), however has a very low probability of material reaching these elements (0.7 %). For a complete listing of the hazard ratings, see Table 9 on page 31 in Part 2.

Debris Flows

Several alluvial/colluvial fans in the Snow Creek vicinity were observed to be framework-supported (boulder supported) indicating that there has been in the recent geologic past a combination of rockfall - rock avalanche - debris flow activity with a large majority of the material being rockfall - rock avalanche transported. Field crews made several observations that, within the recent geologic past, slide initiation sites have occurred from mid-slope to ridge crest.

Factors used to assigned hazard ratings were the same used in evaluating debris flow activity in Tumwater Canyon. Two areas (R-2 and R-11a) were assigned high hazard ratings. Five areas (R-1a, R-1b, R-5, R-7, and R-9) were assigned medium ratings. One area (R-3) was assigned a low to medium rating. The rest of the areas were assigned low ratings (see Plate 2).

Snow Avalanches

Two observations of snow avalanche events have been made by residents in the last 50 years. Site 4, downslope from areas R-4 and R-5, had a snow avalanche in the 1940's; and site 6, downslope from areas (R-2, R-11a, and R-11b) had a snow avalanche occur in the winter of 1982. Neither site had property damage from these events.

Recommendations

Rockfall

The three areas assigned high hazard ratings (R-2, R-11a and R-11b) have homes located downslope from the potential initiation sites. Excavating "sinks" or the placement of earth berms upslope from these homes seems to be the most cost-effective, although this alternative may not be simple because of easement constraints. Construction of rockfall fencing will probably be the most expensive and, considering the possible kinetic energy of rocks reaching these homes, fencing may become the preferred alternative because "sinks" and berms may not stop all rockfall from reaching these houses.

Debris Flows

Field crews observed that little soil remains on middle and upper slopes. Over recent geologic time (past few thousand years) most soil has been deposited in fans along the valley floor. If slope movement is initiated, it will predominately come from the lower slopes. As stated above, excavation of sinks or constructing earth berms will probably be complicated by easement constraints, although this alternative is probably the most cost-effective for both debris flows and rockfall. Because the lower slopes have a low gradient of approximately 20 ° or less, the most feasible alternative would be to retain standing timber.

Snow Avalanches

Only two known events of snow avalanching have occurred in this part of the wildfire area. As with the Tumwater Canyon area, the most effective mitigation will most likely be vegetation planting.

Summary

High hazard areas for both rockfall and debris flow are areas R-2, R-11a and R-11b; therefore, mitigation alternatives should be blended for both slope processes. This will probably be a combination of retainment of standing timber and rockfall fencing.

Wedge Mountain

Current Situation

Rockfall

One of two areas was evaluated for rockfall in the Wedge Mountain area. This area, W-1, has a medium hazard rating based on probability (less than 5%), kinetic energy (283,000 ft-lbs), and potential risk (damage to a canal). If the probability of rock material reaching the canal was higher (e.g., > 10%), then this area would be assigned a high hazard rating. Anecdotal information indicates that the

canal occassionally gets hit by rockfall (a few times per decade); therefore, the estimated probability is most likely similar to natural occurrences.

Debris Flows

Wedge Mountain has no high hazard areas for debris flow activity. Some failure may occur within area W-2, where road fill has been disturbed on pulled culvert crossings. If debris flow activity occurs in W-2 it will be small in volume, but could damage the canal and was therefore assigned a medium hazard rating.

Recommendations

Slope movement occurring in the Wedge Mountain area has not been accelerated by wildfire according to our analysis. Rockfall is similar to natural levels; and debris flows are associated with removal of road fill material. Residents, however, have made observations that trees have fallen into the irrigation canal. Post-fire tree-falling has incurred some damage. Therefore, trees that may be susceptible to falling into the canal should be marked and possibly removed.

PART 2

Part 2 gives a detailed description of the work completed for this project. Readers will find in the text and appendices the information that we gathered, reduced, analyzed and used for developing and assigning hazard ratings, and developing preliminary mitigation alternatives. For a brief description please read Part 1.

INTRODUCTION

During the months of July through October, 1994, over 40,000 acres of forested lands were burned near the town of Leavenworth, Washington. Several hundreds of acres of steep, potentially unstable slopes were exposed to high intensity forest fire in Tumwater Canyon and the lower Icicle River valley. Below many of these slopes are structures and roadways, including State Route 2 (S.R. 2), Icicle Creek road, residential buildings, a national fish hatchery, a municipal water supply, and an irrigation canal. Because these structures and roadways have the potential of becoming damaged by slope movement, the Wenatchee National Forest (WNF) with the Washington State Department of Transportation (WSDOT) organized and financed a team composed of geotechnical engineers and engineering geologists to complete a slope stability hazard assessment of these areas. The objective of this project was a technical report that lists the slope stability hazards that may occur in the future, and provides possible alternatives that may mitigate these hazards. This project falls within a scoping level as required by federal legislation (e.g., National Environmental Policy Act, 1969; and National Forest Management Act, 1976); therefore, information within this report is accurate for planning purposes only. Data from this report will be used in formulating an action plan in early 1995 for management decisions.

PURPOSE AND SCOPE

During the wild fire of July through October, 1994, several agencies and interest groups expressed a concern that slopes within these two areas would become unstable because of the forest fire and future weather events. Therefore, the Wenatchee National Forest Supervisor and Washington State Department of Transportation North Central Region Administrator requested a slope stability assessment. The purpose of this study was to identify and evaluate potential hazards occurring on slopes where stability may be affected from wild fire. The products from this project would be a

technical report and a slope stability hazard map entered into the Wenatchee National Forest (WNF) geographic information system (GIS). A concern of the WNF was the loss of tree root systems and subsequent slope instability. Initially the scope of this project was to work on: 1) the west aspect slope of Tumwater Canyon from ridge crest to ridge toe between mile posts 90 and 96 of S.R. 2; and, 2) the south, southeast, and east aspect slopes within the lower Icicle Creek valley approximately between river mile 0.0 and 6.0. This work, however, was expanded to a study area of ten square miles that included the slopes adjacent to Wedge Mountain south of Icicle Creek. Figure 1 shows the approximate location of the project area. Twenty-three sites were identified for initial mapping during a helicopter reconnaissance, but as field work progressed the project sites were increased to a total of forty-eight.

PHYSICAL ENVIRONMENT BACKGROUND

TOPOGRAPHY

Tumwater Canyon

Elevation in the Tumwater Canyon ranges from 1,120 feet in the canyon mouth to 4,480 feet at the top of Tumwater Mountain on the east side and 6,885 feet on Icicle Ridge on the west side. These changes in elevation occur over distances of approximately 1 mile on the east side and 2 miles on the west side. The west side slopes, however, have a major slope break at an average elevation of 5,600 feet, approximately 1.5 miles from the canyon floor. Therefore, the general slope on the east side of the canyon is approximately 33 °, and on the west side the general slope is 30 ° to the slope break and 26 ° to the ridge crest. However, there are several areas on the west slopes that are 45 ° to 60 °. Both sides also have cliff faces that are 90 ° and, in some isolated areas, have overhanging rock outcrops. Slope geometry is very complex but in general is convex to concave with some middle and lower slopes having a planar geometry.

Lower Icicle Creek

Elevation in the lower Icicle Creek ranges from 1,120 feet where it enters the Wenatchee River to 6,696 feet on top of Icicle Ridge and 5,680 feet on top of Wedge Mountain. Icicle Creek flows to the southeast within a canyon before it enters a broad, flat valley, where it flows to the north and enters the Wenatchee River near the terminus of Tumwater Canyon. The lower valley is approximately 1 mile in

width. Icicle Canyon is similar to Tumwater Canyon and forms steep walls with a flat floor. Both walls have average slopes of approximately 30 ° to 35 ° with isolated cliff faces and overhanging rock outcrops. Slope geometry is also very complex and forms primarily convex and concave slopes except for some lower slopes that are planar.

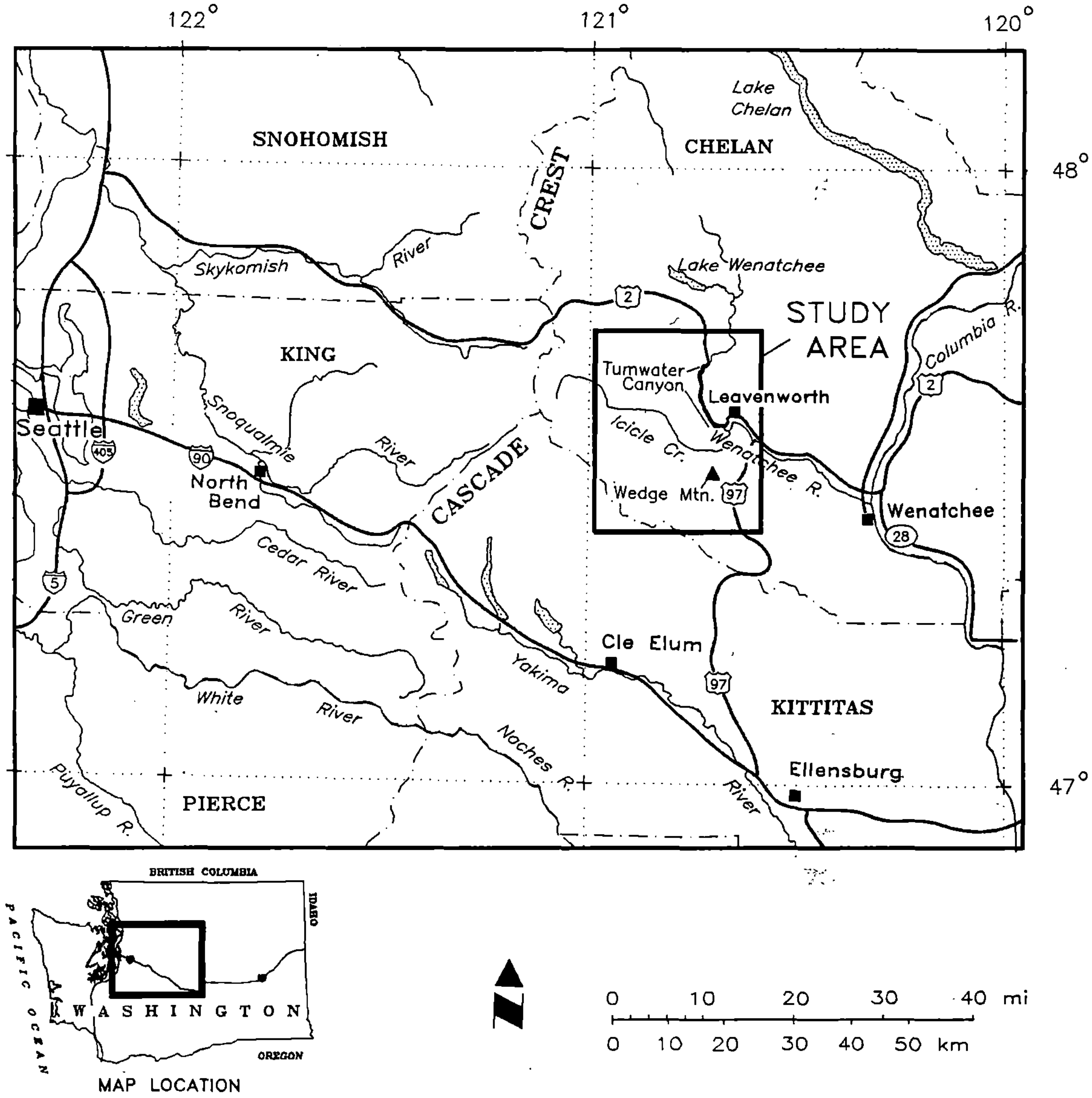

Figure 1. Slope stability project location map.

VEGETATION

The vegetative communities are primarily dominated in the overstory (large, mature trees) by Douglas-fir (Pseduotsuga menziesii), with ponderosa pine (Pinus ponderosa), and grand fir (Abies grandis) becoming more important depending on site conditions and disturbance. A variety of stand structures (sapling to mature tree sizes) may also be present, again, depending on the type and frequency of disturbance and local site conditions. The recent fires have resulted in a mosaic of forest stand conditions because of variability in overstory and understory (shrubs and small trees) tree mortality.

Understory vegetation is largely dominated by shrubs, particularly ocean-spray (Holodiscus discolor), Douglas maple (Acer glabrum var. douglasii), and elderberry (Sambucus cerulea). Important herbaceous plants include heart-leaf arnica (Arnica cordifolia), pinegrass (Calamagrostis rubescens), elk sedge (Carex geyeri), and luina (Luina nardosmia). Understory species dominance will vary depending on site conditions, canopy closure and disturbance. Many of the species listed here, and others, respond favorably to fire and will be abundant in the coming years. In general, some plant species will be "encouraged" by fire while others will become absent returning only when certain plant communities reestablish themselves.

CLIMATE

Climate is typical for east Cascade slopes with cold, heavy snowfall winters, and hot, dry summers. For August the mean low is 49 °F and the mean high is 87 °F. For January the mean low is 16 °F and the mean high is 33 °F. Rainfall is variable in the study area with yearly averages of 25 inches in Leavenworth, 30 to 35 inches in Tumwater Canyon, 25 to 45 inches at Eight Mile Creek in the Icicle Creek drainage, 50 to 60 inches at the headwaters of Snow Creek in the Icicle drainage, and 50 to 60 inches at the head of Cabin Creek in Tumwater Canyon. Snowfall annual average is 93.5 inches. Much of the area lies within the Washington Department of Natural Resources Rain-on-Snow Zone; the last known occurrence of rain-on-snow was in November, 1990.

GEOLOGY

Regional Setting

The regional geology in the Leavenworth - Wenatchee area can be explained in terms of continental responses to plate tectonics (Alt and Hyndman, 1984). During the Cretaceous Period (about 100 million years ago) the western coast line of North America was approximately along today's Washington - Idaho boundary. A small continental plate (microplate) became the Okanogan highlands when it "docked" against the ancient coast line, as it was transported eastwards towards this ancient coast. The subduction zone (area where the oceanic plate is pushed below a continental plate) then "jumped" westward to the new coast line along the western margin of the Okanogan highlands. The Leavenworth - Wenatchee area is approximately where this new subduction zone was located. A second microplate, the North Cascades micro-continent, was then transported to this new coast line where it "docked" during the Eocene Period (40 to 50 million years ago). The subducting activity that was the driving mechanism for bringing these microplates to the ancient coast lines also produced much of the geology in the Leavenworth - Wenatchee area.

A "sliver" of oceanic plate material (ophiolite melange) was thrust on the Okanogan micro-continent as this microplate was being transported towards the ancient coast line in Early Cretaceous time. This ophiolite melange is the Ingalls Tectonic Complex located to the west-southwest of Leavenworth. The Mount Stuart batholith was intruded into the North American plate (docked Okanogan microplate) as subduction was occurring in the late Cretaceous Period. This batholith is the source of the igneous rocks forming Tumwater Canyon and the lower Icicle Creek valley. Once the North Cascades micro-continent became docked on the North American plate, the subduction zone "jumped" westwards. The huge stresses and strains involved in the docking of the North Cascades micro-continent resulted in the formation of the Chiwaukum graben (basin) bounded on the west by the Leavenworth fault and the east by the Entiat fault, forming the Leavenworth valley. The Methow graben was also formed at this time, where the present towns of Twisp and Winthrop are located. Sedimentary rocks that were deposited 40 to 50 million years ago within the Chiwaukum graben are called the Chumstick Formation. These rocks can be found on Wedge Mountain in the study area.

In recent geologic time the project area has undergone glaciation. Glacial deposits within the Icicle Creek valley indicate there has been glaciation at least three times and similar deposits have been mapped in the upper Wenatchee valley (Tabor et al., 1987). The estimated dates for the latest two glaciations are between 130,000 to 150,000 BP (before present time), and 13,000 and 20,000 BP

Bedrock

Figure 2 is taken from the Chelan 30-minute by 60-minute quadrangle geology map (Tabor et al., 1987). Bedrock includes intrusive igneous rocks (tonalite, granodiorite, diorite, and gabbro) on Tumwater Mountain and Icicle Ridge; and Wedge Mountain has sandstone (micaceous feldspathic arenite). Mica Creek drainage within the Tumwater Canyon area has several outcrops of metamorphic rock (talc-tremolite schist and serpentinized ultramafite). Unified Rock Classification (Williamson, 1984) is predominately BBEA (visually fresh state, uniaxial compression of 8,000 to 15,000 psi, 3-dimensional planes of separation, and unit weight >160 pcf) for the igneous rock and CCEA (stained state, uniaxial compression of 3,000 to 8,000 psi, 3-dimensional planes of separation, and unit weight >160 pcf) for the sandstone.

Surficial Geology

Tumwater Canyon has steep walls and a flat valley floor (Figure 3). The Wenatchee River flows through this canyon in a series of pools and riffles except where a small concrete dam is located approximately three river miles upstream from the canyon mouth. Several riffles are adjacent to colluvial and alluvial fans, indicating that fans may have been deposited within the stream course, and influenced stream width and depth. Landslide types include rockfall, rock topple, rock avalanche, debris flows, and slump-earthflows (after Varnes, 1978). Several large deep-seated landslides (several tens of feet deep) are located in the Mica Creek drainage.

Lower Icicle Creek forms a wide valley floor, approximately one mile in width, composed of several terraces where it enters the Wenatchee River near Leavenworth. Icicle Ridge lies upslope from the left bank, and Boundary Butte and Wedge Mountain are situated above the right bank. Icicle Creek is a low-gradient meandering stream in the lower valley but, within the canyon, the creek is a confined high-gradient stream capable of moving large boulders, some as large as 10 feet in diameter. The same landslide types found in Tumwater Canyon are also in the lower Icicle Creek valley.

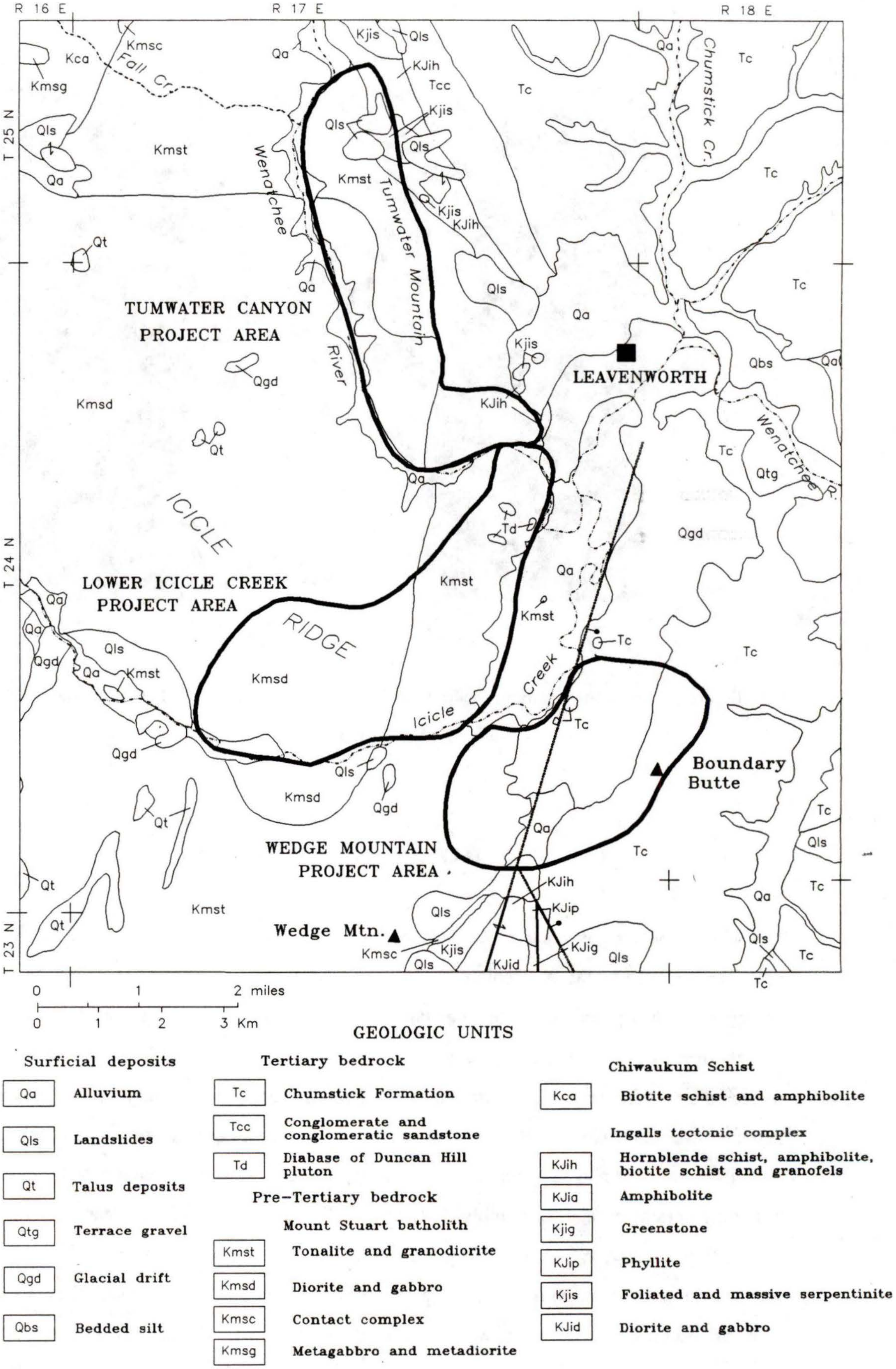

Figure 2. Geological map of the Leavenworth area including project boundaries (Tabor et al., 1987).

Figure 3. Tumwater Canyon looking south (downstream) with small concrete dam in center of photograph.

HAZARD IDENTIFICATION

Rockfalls, debris flows, and snow avalanches have occurred within the study area for thousands of years, as indicated by the large colluvial and alluvial depositional fans that can readily be seen on aerial photographs. It is probable that these activities have been occurring since at least the last glacial activity over 12,000 years ago. Rockfall has probably been the dominant landslide mechanism as indicated by the framework-supported (boulder-supported) colluvial fans along both Tumwater Canyon and the lower Icicle Creek valley. Undoubtedly vegetation type has changed over the last 12,000 years and this change has played an important role in slope processes because tree root strength is an important parameter in slope stability (O'Louglin, 1974; Swanston, 1974; Ziemer and Swanston, 1977; Sidle, 1980; Ziemer, 1981; and, O'Loughlin and Ziemer, 1982;), especially for shallow (e.g., less than 2 feet thick) non-cohesive soils that are common in the study area. The loss of root shear strength has probably occurred many times as wildfires caused root mortality. Therefore, wildfires occurring during post-glacial time have contributed to the magnitude and frequencies of slope processes. Recent human activities (last 100 years) also have influenced some slope stability as the railroad, roads, and canals

were constructed in the Leavenworth area. However, 100 years is less than 1% of the last 12,000 years and a large majority of the material deposited in alluvial and colluvial fans certainly predates the last century.

Many slope processes are perceived by the public to be hazards. When a geologic condition, such as a landslide, has a probability of causing damage or of being detrimental to a resource, such as a road, then it is reasonable to describe the landslide as a hazard and the potential resource damage from the hazard as a risk (Koler, 1994). Hazard/risk assessments are useful for planning purposes so that managers can make prudent decisions for proposed activities. However, the one component that is frequently overlooked in this type of assessment by the public is that geologic processes require geologic time, usually hundreds if not thousands of years, for process completion. Individual wildfires, rainfall, or rapid snowmelt can increase the timing of individual slope movements; but in general, hillslope processes will require long-term changes in climate and slope conditions (e.g., increased ground water) to effect increases (or decreases) in landslide magnitude and frequencies.

NATURE OF HAZARDS

Rockfall

Rockfall is a fall of a newly detached mass from an area of bedrock (Varnes, 1978). Downslope movement is very rapid and is usually a combination of free fall, bouncing, and rolling. In some cases the material is held in place by vegetation as shown in Figure 4. If this vegetation is removed (e.g., through wildfire-caused mortality), then the material may continue downslope movement.

Debris Flows

Benda and Miller (1991) give the following definition for debris flows:

> "A highly mobile slurry of soil, rock, vegetation and water that can travel miles from its point of initiation, usually in steep (>5 °) confined mountain channels. Debris flows form by liquefaction of landslide material concurrently or immediately after the initial failure. Debris flows contain 70 to 80% solids and 20 to 30% water. Entrainment of additional material as the debris flow moves through first and second-order channels can increase the volume of the original landslide by 1000% or more, enabling debris flows to become more destructive with

travel distance. Other names given to debris flows: debris torrents, sluice-outs, and mud-flows."

Figure 4. Potential 4 foot diameter rockfall supported by a tree near the ridge top in area T-3.

Figure 5 shows a potential rockfall-debris flow-snow avalanche area. In many of the areas studied there is a combination of rockfall-debris flow movement hazard potential.

Snow Avalanches

Selby (1982) gives the following definition for snow avalanches:

"Snow avalanches can entrain boulders, trees, and other debris as well as destroying stands of trees. They also contribute this debris to the accumulations at the base of slopes...Large avalanches usually occur on slopes of 30 ° to 50 °, small avalanches on slopes of 50 ° to 65 °,

and minor shedding of small snow accumulations on steeper slopes where accumulation is most difficult. On slopes of less than about 30 ° snow avalanches are not common although dry snow can avalanche at angles as low as 25 ° and wet snow at angles as low as 10 °. The optimum conditions for geomorphically significant avalanche snow accumulation are on slopes of 30 ° to 50 ° with an even surface, and hence above the tree line, with well-established tracks, below the accumulation area covered by a mantle of loose debris."

Snow avalanches may occur in areas similar to those shown in Figure 5. Middle and upper slopes average 33 ° and the trees are probably dead from intense wildfire. If the stand of trees is removed and no replanting occurs, then an area such as this falls into Selby's "optimum conditions" category.

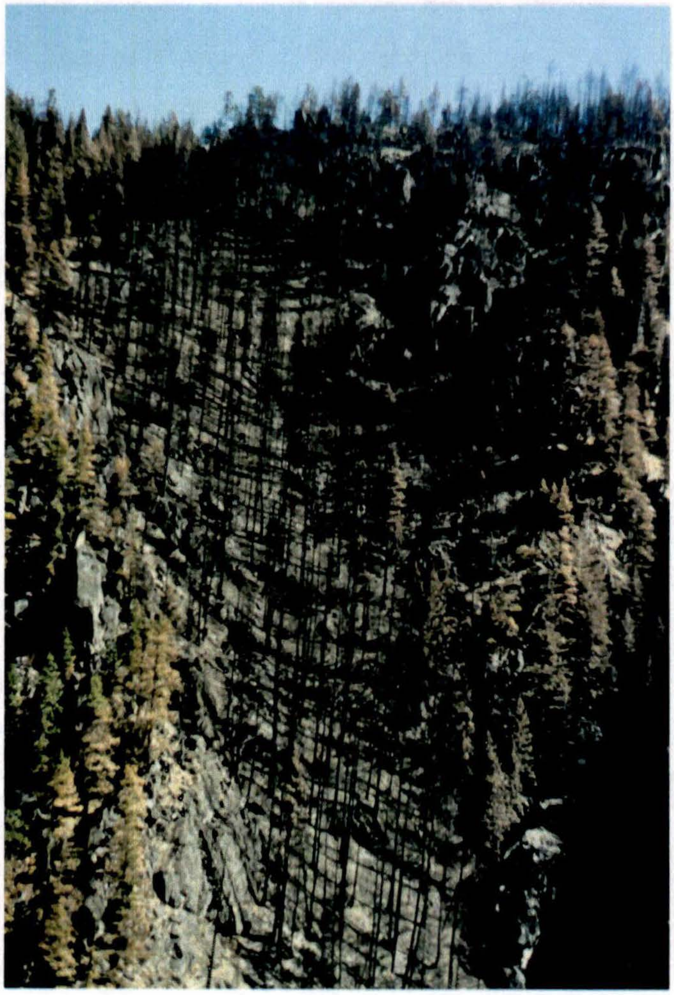

Figure 5. Potential rockfall-debris flow-snow avalanche area within T-1.

SLOPE MOVEMENT HISTORY

The identification of active slope processes and frequency of occurrence was important in assessing the hazard potential. The following part of this report describes the available information from residents, WSDOT, and local newspaper articles.

AREA SLOPE STABILITY SURVEYS

There have been several verbal reports of slope movements along the walls in the Tumwater Canyon and lower Icicle Creek valley in response to heavy rainfall or rapid snow melt, including rain-on-snow events. In the early decades of this century, a railroad corridor was located within Tumwater Canyon where State Highway Route 2 is now located. Anecdotal reports state that coal embers from train engines started several wildfires in the canyon and numerous landslides occurred as a result. In the 1930's the railroad alignment was removed from the canyon because landslides and snow avalanching occurred repeatedly. Both areas have prehistoric landslides that were mapped by Tabor et al. (1987).

Residents in lower Icicle Creek valley were surveyed for information regarding recent and historical accounts of rockfall and debris flow activity. Tumwater Canyon residents did not provide information for this survey. Surveys were conducted in late September by Jessie DeMuth, Information Assistant with the Interagency Fire Rehabilitation Team; Brent Billingsley, Washington Department of Natural Resources (DNR); and Linn Goettlich, Entiat Ranger District. The average length of years in residence of the respondents is 24, but varies from one year to over 50. Residents recalled events going back to the 1940's. Survey results from the 22 respondents are summarized in Tables 1 and 2. Location for each survey site is provided in the rockfall and debris flow hazard assessment plates in the back cover jacket.

In addition to these resident surveys, information was gathered from available newspaper reports of debris flows and snow avalanches; this information is listed in Table 3. Some of the events listed in Table 3 are also recorded in the resident survey in Table 2. In addition to the anecdotal information from residents and newspapers, there is an inventory and atlas available from WSDOT. Below are summaries of available survey information for rockfall, debris flows, snow avalanches, and flooding. Except for the WSDOT information, the summaries are anecdotal and have not been confirmed by slope stability specialists.

Rockfall

Little anecdotal information about rockfall in Tumwater Canyon is available. The railroad history described above was one information source, and general comments from Leavenworth area residents was another source. These residents, including school bus drivers, rarely travel S.R. 2 after a heavy rainfall or snowfall because of potential slope movements that include rockfall. Data collected in the WSDOT unstable slope inventory (Washing State Department of Transportation, 1994) indicates that potential rockfall can be attributed to ravel of colluvium exposed in oversteepened road cuts.

Rockfall in the Icicle Creek area was mentioned in 68 percent of the resident survey and is displayed in Table 1. Most rockfall events were usually associated with wildfire or heavy rainfall-snowmelt storms. The most recent rain-on-snow event was the November, 1990, storm. Only two respondents noted an increase in rockfall associated with this event. At the time of the survey, post-fire events included an increase in rockfall activity noted by seven residents.

Rockfall-related property damage, over the last 45 years has not been common. Pre-fire damage occurred at two locations; one case was due to city water pipe construction, the other was a rock that had to be dynamited in the Snow Creek parking lot. Occasionally there has been damage to trees. Post-fire damage occurred when rockfall caused a breach in the irrigation canal above the Icicle Island community. This breach resulted in foundation damage to a home and flooding on several properties.

Debris Flows

No information was available for debris flows in the Tumwater Canyon other than the anecdotal comments about railroad, and heavy rainfall- and snowfall-related slope movements briefly described above.

Up to six separate debris flow events were recalled by Icicle Creek residents, spanning from around 1950 to 1991 (see Table 2). No property damage was mentioned in association with these events. The debris flows mentioned in the surveys were most likely initiated low on the slope, limiting the volume and runout of the mass. Slope stability crew members found evidence of smaller-scale pre-fire soil failures generated on the lower slopes on Icicle Ridge. Depositional areas on the slopes were noted in transects of R-10, R-7, and on the trail between those two burn units. Table 3 lists several debris flows that have occurred in the past and were recorded in local newspapers. Most of these occurred during thunderstorms or rain-on-snow events or during months of seasonal rainfall. The one exception was attributed to logging activity.

Table 1. *Icicle Creek resident survey of past damage from rockfall activity.*

Site	Approximate Date of Known Event	Assumed Cause	Damage to Property	Comments
1	September 2 or 3, 1994	tree fall	house foundation damaged, property erosion, and canal was breached	first time occurrence in 16 years
3	wildfire in 1988 or 1989.	wild fire	destroyed a fringe on the patio	
7	November 1990	heavy rainfall	rocks did not reach building	a rock chair-size and several smaller fell
8	1990	city water pipe construction loosen rock	large rock damaged a storage shed	city compensated for damage
9	1994	wildfire	none	medium to large-size rock
9	years ago	spring rainfall	none	
11	summer and fall of 1992	don't know	none	rare events, coming from trail upslope
12	1994	wild fire	none	a single 2'x3' boulder
13	1954	rain or snowmelt?	boulders stopped by trees	a couple of large boulders
16	September 1994	wild fire	none	refrigerator-size boulder
16	last 20 years	variable	destroyed a few trees	large boulders
17	summer 1994	wild fire	did not reach slope toe	during and after wild fire, largest was 3 ft. in diameter
18	spring and fall of 1994	wild fire	none	rockfall occurs even when slopes are dry
19	spring	snowmelt	none	nothing major
20	few times a year	wild fire and human activity	none, but rocks deposit all around house	increase rockfall after wild fires
21	1994	don't know	none	1 ft. to 3 ft. boulders
22	spring 1989	don't know	boulder in parking lot had to be removed after dynamited	car-size boulder

Table 2. *Icicle Creek resident survey of past damage from debris flow and snow avalanche activity.*

Site	Approximate Date of Known Event	Assumed Cause	Damage to Property	Comments
1	1970	unknown	mud on road and parking lot	
3	1988 or 1989	spring	none	uncertain about date
4	1940's	snow avalanche	none	only know event
6	winter of 1982	snow avalanche	none	stopped 100 ft upslope
14	1979 or earlier	spring rainfall	mud on road	only known event
15	summer of 1991	rainfall	none	
18	1969?	unknown	mud on road.	very deep and warm, moving very slowly
21	1954?	unknown	none	Mud came downslope as far as the road ditchline. Large landslide.

Table 3. *Newspaper article reports of debris flow activity in the Leavenworth area.*

Date	Location	Description
mid-winter, 1971	Lion Creek	Resulted from a rain-on-snow event.
March 2, 1972	Icicle Creek mouth	Debris flow crossed Icicle Road just upstream of Icicle Creek mouth.
March 2, 1972	Clark Canyon	100 ft by 1000 ft landslide material 1 mile east of the Chumstick Valley Road.
1974 or 1975	Spromberg Creek	Debris flow occurred after logging activity on the South Fork.
early spring, 1977	Lion Creek	Resulted from a rain-on-snow event.
summer, 1983	hill near Icicle Creek	Debris flow was initiated by a thunderstorm.
summer, 1988?	near Icicle Island subdivision	Debris flow was initiated by a thunderstorm.
November, 1990	Icicle Creek	
August 6, 1991	east of Leavenworth	Debris flow was initiated by a thunderstorm with 1 inch hail stones and 0.7 inch rainfall in half an hour. Material closed SR 2.

Snow Avalanches

The WSDOT Avalanche Atlas (University of Washington Geophysics Program and Department of Civil Engineering, 1975) identified snow avalanches from the west side of the canyon as being more prevalent than those from the east side. Four historic avalanche sites (TW-6, TW-7, TW-8, and TW-9), where avalanches have reached the Wenatchee River, are located near to or within the Drury Falls Creek drainage shown in Figure 6. These sites were assigned high hazard ratings because they have produced avalanches reaching the river in the past. The atlas assigned a high-infrequent hazard for these sites. Areas TW-6 and TW-7 produced large snow avalanches that occurred in January of 1971 and 1972. These events were produced by heavy snowfalls followed by rain, and in both cases the avalanches reached the river. Drury Falls Creek has several reported avalanches reaching the river during the past 50 years. Avalanches in areas TW-6, TW-7, and TW-9 were identified as having the potential of reaching S.R. 2 during heavy snowfall followed by rainfall. Avalanches within TW-8 reached the river, but did not reach S.R. 2.

On the east side of the canyon, there are 34 sites identified in the atlas as having low- to high-frequent hazard ratings. These potential avalanches are variable in size, and a majority occur within the lower 500 feet of the slope. There are some avalanches that begin higher on the slope, but they are rare. In most cases, snow avalanches on this side of the canyon also occur after heavy snowfall followed by warming and rainfall. Some avalanches are "small" to "medium" in size and can reach S.R. 2, temporarily closing the highway. In most avalanche events the material is composed of snow, rock, and some soil. One fatality occurred due to avalanche activity in the vicinity of TU-5 to 10. Therefore, these five sites are assigned high hazard ratings and are included in Figure 6.

Little information on snow avalanche events were collected in the Icicle Creek resident survey (Table 2). A snow avalanche in the 1940's deposited onto the Snow Creek parking lot, and another snow avalanche stopped 100 feet up the hill behind Bayne Road in 1982. Of the events listed in the resident survey, only the snow avalanche track near the Snow Creek parking lot was visible on historic aerial photographs of the area.

Flooding

According to residents, post-fire flooding occurred in Icicle Creek as the result of a large burnt pine falling into the irrigation canal east of Mountain Home Creek. The tree ponded water that caused severe gullying of the slope and a forest road below.

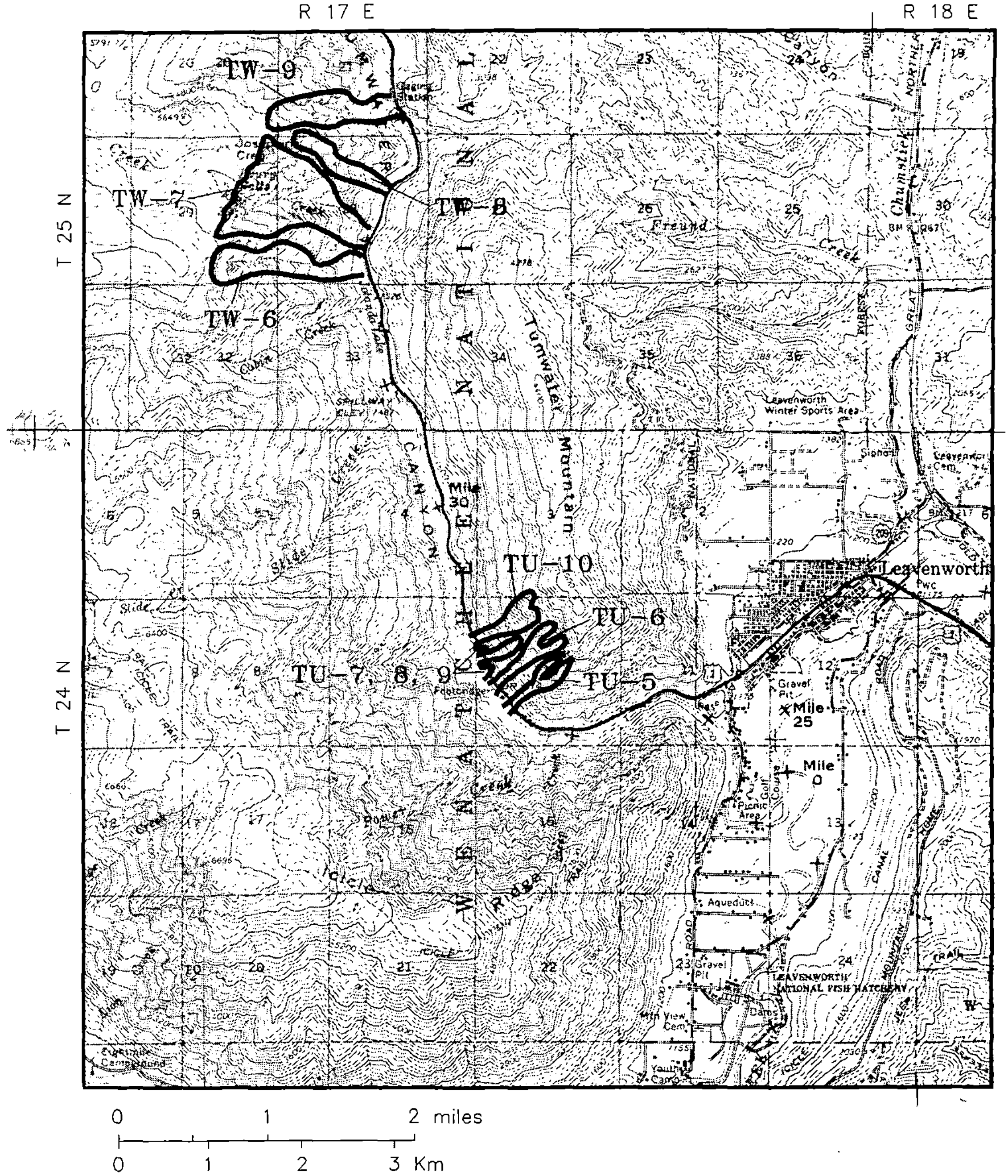

Figure 6. High hazard sites for possible snow avalanche events in Tumwater Canyon.

HISTORIC LANDSLIDE INVENTORY

Historical aerial photographs were analyzed for frequency and distribution of mass-movement within the survey area. Aerial photographs from the following years were available: 1994 post-fire verticals and obliques, 1992, 1986, 1979 (not including upper Icicle Creek), 1975, 1970 (incomplete coverage), 1954 (not including upper Icicle Creek), and 1949 (incomplete coverage). The locations of inventoried events are recorded on Plate 3 and correspond to inventory data in Table 4.

In the 45 years of photographic record, no slope failures were visible on the east-facing slope of Icicle Ridge above the main residential development. As mentioned in the discussion on the area resident survey, the debris flow events recalled by residents initiated low on the slope and were limited in volume and runout. The photographic inventory does not resolve the occurrence of small-scale mass movements, such as the ones reported in the resident survey.

Larger scale debris flow-type events have occurred on the east slope of Icicle Canyon above Snow Creek and the west slope of Tumwater Canyon. Many of the channelized events in Tumwater Canyon lack a distinct initiation location, suggesting an in-channel mobilization of accumulated debris. Of the 14 or more individual events, only one debris flow appearing in the 1992 photographs in Falls Creek in Tumwater Canyon; this flow ranout all of the way to the Wenatchee River. The timing of this event suggests an association with the November, 1990, storm and flooding. The debris flows have been deposited on the upper slopes of the fans or depositional areas, and many have dissipated or deposited midslope above the fans.

Smaller-scale features have been noted on the east slope of Tumwater Canyon above S. R. 2. A number of shallow mid-slope failures appeared in Section 10 in 1986, and none travel the full slope length to the highway. Several failures occurring at the base of the slope adjacent to S.R. 2 were interpreted as road cut failures and were not inventoried for the purpose of this study.

The remaining slides were either shallow low-slope failures or those deposited in mid-slope locations. The debris track mapped as number 39 may be the location of the snow avalanche recorded in the resident survey near the Snow Creek parking lot. It appeared as a bright track in 1949 and remained visible through 1994. A debris slide occurring off the east side of Tumwater Ridge (no. 34) also remained visible through 1994. The landslide scars have been slow to revegetate, increasing confidence in identifying visible events.

Table 4. *Historical landslide inventory from aerial photographs.*

Landslide Number	Photograph Year Appearing	Mass-wasting Process	Level of Certainty	Comments
1	1949	debris flow	probable	
2	1970, 1992	debris flow	probable	1992 event traveled to river
3	1970	debris flow	probable	
4	1970	debris flow	probable	
5	1970, 1986, 1992	debris flow	probable	persistent since 1970, bright again in 1986 & 1992, may be snow avalanche
6	1979	rockfall / debris flow	probable	show up as chutes to highway in 1979 but may have been there earlier
7	1979, 1992	debris flow	probable	may be snow avalanche track
8	1992	debris flow	probable	may be snow avalanche track
9	1986	rockfall / debris flow	probable	shallow failure, stops on fan above highway
Number Break	NA	NA	NA	NA
23	1992	debris flow	probable	appears to initiate in channel, shallow sliding, stops mid-slope
24	1992	debris flow	probable	shallow sliding, deposits mid-slope
25	1992	debris flow	probable	shallow sliding, deposits mid-slope
26	1986	debris slide	probable	deposits mid-slope
27	1986	debris slide	probable	deposits mid-slope
28	1986	debris slide	probable	deposits mid-slope
29	1986	debris slide	probable	deposits mid-slope
30	1986	debris slide	probable	deposits mid-slope
31	1986	debris slide	probable	deposits mid-slope
32	1992	debris flow	probable	appears to initiate in channel
33	persistent	shallow rockfall and debris flow	probable	
34	1975	debris slide	certain	deposits in channel mid-slope
35	1949	debris slide	certain	slide in coarse debris or talus
36	1949	debris slide	certain	slide in coarse debris or talus
37	1986	debris flow or rockfall	probable	does not impact stream or improvements
38	1975	rockfall	probable	

FIRE-INDUCED INFLUENCES

With potential in-channel initiation of debris flow events such as those seen on the west slope of Tumwater Canyon, an increase in the accumulation of debris in the channels due to post-fire erosion may cause an increase in the frequency and perhaps the magnitude of channelized events. Most of the channels in the high-intensity burn areas studied do not support perennial stream flow, so future failures would most likely be associated with intense late-summer thunder showers or rapid rain-enhanced snowmelt.

Given the low frequency of debris flow type of movements on the east slope above S.R. 2, snow avalanche and rockfall processes appear to be the more frequent processes contributing to colluvial fan construction. Debris flows initiating in the upper slopes where most of the intense burn areas were surveyed occur infrequently and many dissipate or deposit prior to reaching the bottom of the slope. These less-frequent events, however, may also produce the larger-scale response. The return period of high-magnitude debris flow-events necessary to construct these fan features may be on the order of several hundred years or more. Trenching fan deposits for debris flow statigraphy would be the best method to gain confidence in this estimate and may associate events with earlier fires.

METHODS

FIELD INVESTIGATION

Potential project areas were identified during a helicopter reconnaissance. Oblique aerial photographs were taken during reconnaissance for use in determining the extent of field work needed, access logistics, and equipment and personnel needs. Project areas were assigned to a priority list based on the reconnaissance and historical information. Adjustments to this priority list were made as field work progressed. Historical information was obtained through a search of available highway reconstruction and maintenance history, a comprehensive aerial photography analysis for disturbance history, and surveys. This information was used to determine frequencies and patterns of past slope stability events and associated conditions.

Most of the field methods used for this project followed the methods described within the USDA Slope Stability Reference Guide for National Forests in the United States (Hall et al., 1994). Some

modification of these methods were made because of the project area size (approximately 10 square miles), likelihood of snowfall (field work was started the last week in September), and potentially hazardous field conditions (steep slopes and rock cliffs). A field inventory process and data sheet were developed by project members; an example of the data sheet can be seen in Appendix A.

For each area the following steps were completed:

1. Transects for collecting field information within each area were identified during helicopter reconnaissance and by office aerial photography analysis.
2. During field work the transects were divided into "cells". These cells had similar characteristics such as rock and soil type, slope, depth to ground water, and shape.
3. Slope angles and distances, discontinuities (e.g., rock joints and fractures) were measured, and soil depths were estimated along the transect following the field-developed cross section method (Williamson et al., 1994). Dip directions and dip angles of discontinuities were measured using a Brunton compass.
4. Rock and soil units were identified using the Unified Rock Classification System (Williamson, 1984), and the Unified Soil Classification System (Howard, 1986).
5. Slope surface roughness and average boulder radius were estimated.
6. Observations included types of slope movement, burn intensity level of vegetation, tree stand density, presence of seeps and springs, and slope geometry (i.e., concave, convex, planar, complex).
7. Photographs were taken to record slope and material conditions, and to record other useful information (e.g., trees supporting boulders, soil macropore development from completely destroyed root systems, and other unique features).

Safety for the field crews was the highest priority. Therefore, all crew members were given training in safe rock-climbing methods. Field crews typically had three members so that field data could be collected rapidly and in a safe manner.

ANALYSES

DLISA

Deterministic Level I Stability Analysis (DLISA) is a computer program that solves the infinite slope equation for soil depth, surface slope, root cohesion, ground water ratio, friction angle, soil cohesion, and factor of safety (Hammond et al., 1992). DLISA was used in a sensitivity analysis for this project using these parameters and values. For example, most of the parameters were estimated from the data collected during field work. If data for one parameter were unknown or unclear, then a range was determined for that parameter using a range of values for the factor of safety, and keeping all other parameters constant. This was done for the ground water ratio (ratio of the apparent thickness of saturated soil to total soil thickness) and slope, two important parameters in calculating the factor of safety. Tables 5, 6 and 7 show the results from the sensitivity analyses.

Table 5. *Critical soil depths (depths where driving forces = resisting forces) using deterministic Level I stability analysis (after Hammond et. al., 1992). Soil depths are in feet.*

Condition	Ground Water Ratio	Slope Angle 30% (17°)	40% (22°)	50% (27°)	60% (31°)	70% (35°)	80% (39°)	90% (42°)	100% (45°)
SM & ML	0.00	>15.0	>15.0	>15.0	>15.0	14.1	6.5	4.4	3.5
Pre-burn	0.25	>15.0	>15.0	>15.0	>15.0	6.4	4.2	3.3	2.8
$\phi = 32°$	0.50	>15.0	>15.0	>15.0	6.6	4.1	3.1	2.6	2.3
$C_s = 40$ psf	0.75	>15.0	>15.0	7.4	4.2	3.0	2.5	2.1	1.9
$q_o = 40$ psf ($C_r = 40$ psf)	1.00	>15.0	9.3	4.5	3.1	2.4	2.0	1.8	1.7
SM & ML	0.00	>15.0	>15.0	>15.0	>15.0	7.2	3.4	2.4	1.9
Post-burn	0.25	>15.0	>15.0	>15.0	7.9	3.3	2.2	1.8	1.5
$\phi = 32°$	0.50	>15.0	>15.0	10.3	3.3	2.1	1.6	1.4	1.3
$C_s = 40$ psf	0.75	>15.0	>15.0	3.5	2.1	1.6	1.3	1.2	1.1
$q_o = 0$ psf ($C_r = 0$ psf)	1.00	>15.0	4.2	2.1	1.5	1.2	1.1	1.0	0.9

ϕ = soil friction angle C_s = soil cohesion q_o = tree surcharge C_r = tree root cohesion

Table 6. *Critical depths (depths where driving forces = resisting forces) for decomposed bedrock and residual soil (soil friction angle, $\phi = 40°$, soil cohesion, $C_s = 150$ psf, and tree surcharge, $q_o = 40$ psf for pre-burn conditions and 0 psf for post-burn conditions) in Tumwater Canyon using deterministic Level I stability analysis (after Hammond et. al., 1992). Depths are in feet.*

Condition	Ground Water Ratio	Slope Angle 30% (17°)	40% (22°)	50% (27°)	60% (31°)	70% (35°)	80% (39°)	90% (42°)	100% (45°)
Pre-burn	0.00	>15.0	>15.0	>15.0	>15.0	>15.0	>15.0	>15.0	>15.0
C_r = 40 psf	0.25	>15.0	>15.0	>15.0	>15.0	>15.0	>15.0	>15.0	10.1
Post-burn	0.00	>15.0	>15.0	>15.0	>15.0	>15.0	>15.0	>15.0	12.7
C_r = 0 psf	0.25	>15.0	>15.0	>15.0	>15.0	>15.0	>15.0	12.3	8.1

C_r = tree root cohesion

Table 7. *Critical depths (depths where driving forces = resisting forces) for talus or boulders (soil friciton angle, $\phi = 38°$, soil cohesion, $C_s = 0$ psf, and tree surcharge, $q_o = 40$ psf for pre-burn conditions and 0 psf for post-burn conditions) in Tumwater Canyon using deterministic Level I stability analysis (after Hammond et. al., 1992). Depths are in feet.*

Condition	Ground Water Ratio	Slope Angle 30% (17°)	40% (22°)	50% (27°)	60% (31°)	70% (35°)	80% (39°)	90% (42°)	100% (45°)
Pre-burn	0.00	>15.0	>15.0	>15.0	>15.0	>15.0	>15.0	4.6	2.6
C_r = 40 psf	0.25	>15.0	>15.0	>15.0	>15.0	>15.0	4.4	2.5	1.8
Post-burn	0.00	>15.0	>15.0	>15.0	>15.0	>15.0	0.0	0.0	0.0
C_r = 0 psf	0.25	>15.0	>15.0	>15.0	>15.0	0.00	0.0	0.0	0.0

C_r = tree root cohesion

In the sensitivity analyses the pre- and post-burn conditions were evaluated with the assumption that complete loss of the tree root cohesion, C_r, occurs in post-burn situations. This was a conservative assumption because not all tree roots are completely destroyed during wildfires. In some areas of high-intensity burns, however, this extreme case did exist, as shown in Figure 7.

After the sensitivity analyses were completed, the ranges of critical soil depths were compared with data from field inventories. In many cases the field data indicated that the soils were much shallower than the critical depths produced in the analyses. Because the factor of safety used in the analyses was set at 1.0 (driving forces = resisting forces) and soil depth field data are less than those modeled, it is highly probable that most slopes are stable.

Although most slopes are probably stable, it is still important to find the potential initiation sites for debris flows. Potential debris flow initiation sites are commonly assumed to be in areas of wet to saturated soil (ground water ratio of 0.5 to 1.0). The sensitivity analyses show that in both pre- and post-burn conditions, only the very steep slopes (> 60%) have shallow soils with increased ground water ratios.

The soils inventoried were identified in the laboratory (see test summary sheets in Appendix B) as non-cohesive, sands and gravels (SM and GM, Unified Soil Classification; after Howard, 1986). Coarse-grained soils will typically have high hydraulic conductivities; and therefore, a quick rise in the ground water may occur in response to heavy rainfall. The hydraulic conductivities may increase significantly in areas where macropore development has occurred (see Figure 7). Therefore it appears logical that the steep slopes with *deep* soils, where macropores probably developed, were the most likely initiation sites for debris flows. To test this assumption further, the data were then evaluated in the stochastic model, Level I Stability Analysis (LISA) explained below.

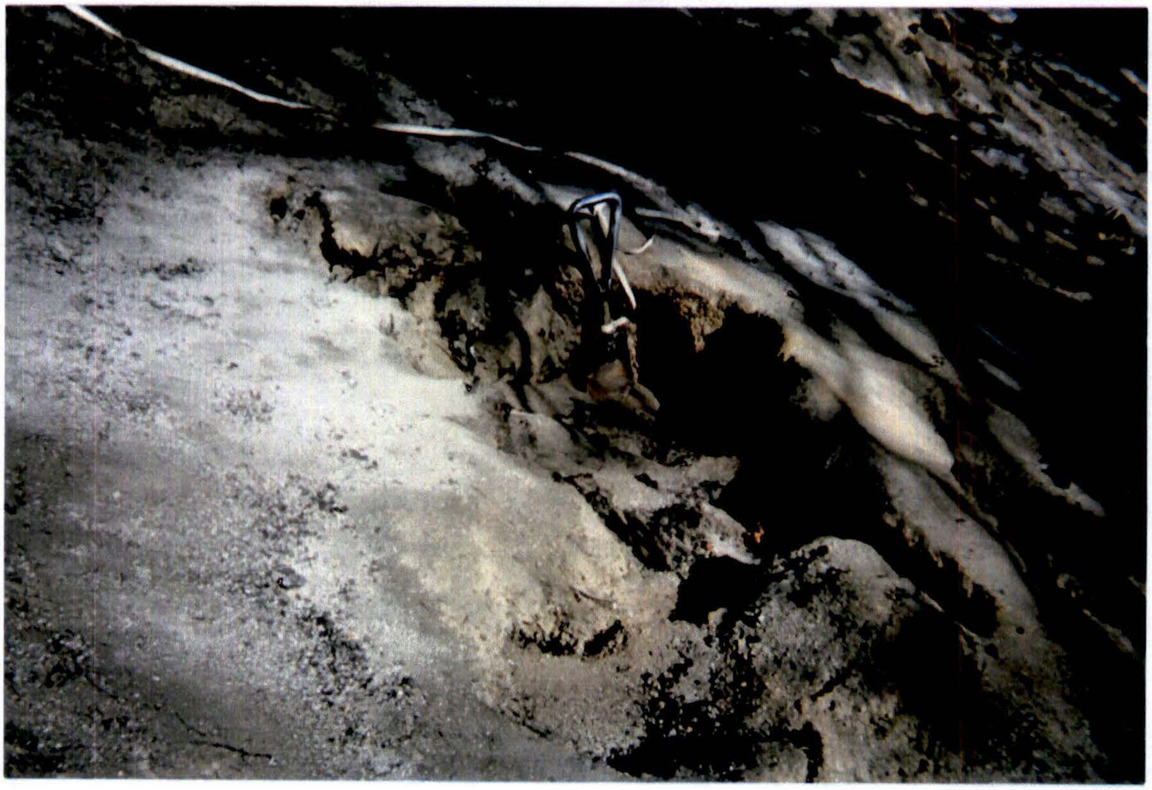

Figure 7. *Complete tree root loss and macropore development from wildfire.*

LISA

LISA is a computer program that enables the user to compute the probability of slope failure using up to 1000 iterations of the Monte Carlo simulation of the infinite slope equation (Hammond et al., 1992). The parameters used are the same as those used in DLISA explained above. In preparing parameter data for LISA input, the user defines the frequency distribution of the parameters. In other words, the user can describe the distribution as constant, uniform, normal (bell-shaped), etc. As with any model, available field data are very important in LISA. If there are "holes" in the field data, the user can use other information such as time-sequence aerial photographs, soil inventory maps, geology maps, and previous earth science reports (i.e., soil science, geology, hydrology, and engineering). The probabilities that are derived from LISA are conditional because parameters do not always remain static.

LISA was used with DLISA to determine potential sites of debris flow initiation. Probabilities less than 0.25 were assigned as low, medium probabilities were between 0.25 and 0.50, and high probabilities were greater than 0.50. In some sites these relative ratings were modified with justification based on field observations and aerial photographs.

Benda - Cundy Debris Flow Runout Model

The Benda - Cundy debris flow runout model can be used to estimate runout distances of potential debris flows (Benda and Cundy, 1990). An estimated runout distance and entrainment volume (material being transported) can be determined using a topographic map and aerial photographs. This model was developed from observations made in the Oregon Coast and Washington Cascade Ranges. Once a debris flow is initiated it will continue to go downstream if the following conditions are met: 1) stream gradient is greater than 3.5 °; and 2) stream junction angle is less than 70 °. The model has an average entrainment volume per stream length of 86 ft^3/ft.

Some calibration of this model was made for this project based on field observations. In some areas these observations indicated that less material was available for entrainment than the average used in the model. Also, gradients measured on a number of accumulation surfaces or colluvial fans varied from 15 ° to 25 ° indicating deposition occurs on steeper slopes, including mid-slopes, that have gradients greater than than 3.5 °.

Colorado Rockfall Simulation Program (CRSP)

The Colorado Rockfall Simulation Program, CRSP, uses field data for evaluating potential rockfall bounce height and velocities (Andrew and Beck, 1993). Once these values are determined, the specialist can then design rockfall fences or rockfall catch ditches. Two boulder sizes, average and maximum, were measured in the field and used in the office analysis in this project. Other field data included cell boundaries (changes in slope or materials), surface roughness values (variation in slope angle), and tangential coefficient of friction. In most cases 100 iterations of CRSP were completed to determine the number of rocks that pass an analysis point and the average kinetic energy. In some areas, less than 100 iterations were run because there were fewer boulders (<100).

The confidence levels of the analyses were based on several limiting criteria: the rockfall path can occur up to 100 feet left or right of the surveyed section, the model parameters were adjusted to fit the local terrain (forested slopes) and, frequencies and probabilities were gauged against historical frequencies and field observations. Output files from each area are found in Appendix C. In several areas where there are dense stands of trees, the values used in CRSP were adjusted accordingly.

ROCKPACK

ROCKPACK is a computer program that uses stereonet projections of three-dimensional data to evaluate potential rock failure (Watts and Associates, 1986). A few sites in this project had bedrock discontinuities (e.g., fractures, joints, and bedding planes) that had a potential for toppling, planar, or wedge failure. Field crews measured these discontinuities with Brunton compasses and completed several "pull" tests to obtain the friction angle, ϕ, using a force diagram analysis. The average ϕ was 36 °. Stereoplots are included in Appendix C, Rockfall Analysis.

ROCKFALL HAZARD ASSESSMENT

The critical question in this assessment is "Did, or will, the effects of the fire have a net increase in frequency and magnitude of rockfall or rock slope failure?"

Rockfall Runout Estimates

Rockfall analyses were from initiation points to areas of concern along the slope toes (e.g., roads and structures). Initiation points were identified in the field and included: 1) rock outcrop spalling due to thermal expansion; 2) increased pore pressures in discontinuities due to thermal expansion; 3) tree impact loading of adjacent rock outcrops due to tree blowdown or snow load; 4) burned trees supporting rock; 5) wind-levering of rocks by trees that were no longer supported by viable root systems; and, 6) undercutting of soil-supported rocks due to surface erosion; In some cases the initiation points were located where rock topple, planar or wedge failure may occur (see Figure 8), and discontinuity measurements were taken in these areas for later office evaluation using ROCKPACK. For average size boulders the modeled distances did not reach sites of concern, except for a very few cases. Maximum size boulders, however, usually had sites of concern within runout distances.

Figure 8. *Rock outcrops with dip-slope discontinuities that were evaluated for stability using ROCKPACK (Watts and Associates, 1986).*

Hazard Ratings and Probabilities

The hazard rating from the rockfall analysis is based on the frequency of simulated and historical occurrence and the proximity of a road or structure to the rockfall path and runout distance. These hazard ratings are simply given as low, medium, and high. Probabilities were calculated so that hazard ratings for average and maximum-size boulders could be compared (see Tables 8, 9, and 10).

Average sizes are assumed to be representative of 50% of the boulder population. All maximum sizes were assumed be representative of no more than 10% of the boulder population. Multiplying the percent frequencies of the average-size boulders by 0.50 gives the probability for this size reaching a site of concern. Multiplying the percent frequencies by 0.10 gives the probability for a maximum-size boulder reaching a site of concern.

Hazard ratings of high, medium, and low are different for Tumwater Canyon, Icicle Creek, and Wedge Mountain areas because slope conditions were not similar from one area to the next. For Tumwater Canyon, hazard ratings were assigned by three factors: 1) large rock source volume; 2) kinetic energy >50,000 ft-lb. (rockfall boulder energy); and 3) rockfall having a probability >4% of reaching a site of concern. For Icicle Creek the ratings were also assigned by three factors: 1) location of homes in runout areas; 2) probability >5% reaching a site of concern; and 3) average kinetic energy >20,000 ft-lb. Wedge Mountain had only one area analyzed and was given a medium rating based on a probability of <5%, kinetic energy (283,000 ft-lb.), and potential risk (damage to a canal). High ratings for Tumwater Canyon and Icicle Creek required having three factors, medium rating required two factors, and low rating had one factor or less. One area in Icicle Creek was assigned a low-to-medium hazard rating, although it had only one factor, because of the location of several homes and a road in the runout area.

TUMWATER CANYON

Ten of the thirteen project areas in Tumwater Canyon were evaluated for rockfall. Of these ten, three areas have potentially high levels of rockfall hazard (T-6, T-10, and T-11). Two areas (T-3 and T-4) have moderate levels, three areas (T-1, T-12, and T-13) have low levels, and four areas (T-2, T-7, T-8, and T-9) had no rockfall hazards. The area T-5 was included in the rockfall analyses of T-4 because of a shared rockfall pathway.

Boulder size was an important factor in determining hazard level. For all of the areas, the average boulder size ranged from 1 to 2 feet in diameter. In T-6, a large 12-foot diameter boulder may have the

Table 8. *Rockfall hazard assessment for Tumwater Canyon*

Rock Diameter (ft)	Site Concern	Rock Number in Analysis	Rock Number Passing Analysis Point (Areas of Concern)	Percent Frequency	Average Kinetic Energy (ft-lb.)	Probability and Hazard Rating	Mitigation Alternatives (see page 41 for descriptions)
			T-1				
Aver. = 2	Road	100	0	NA	NA	0%, Low	
Max. = 4	Road	100	0	NA	NA	0%, Low	
			T-3				
Aver. = 2	Road	100	0	NA	NA	0%, Low	
Max. = 8	Road	100	15	15	962,000	1.5%, Med.	3
			T-4				
Aver. = 2	Road	100	7	7	12,000	3.5%, Low	
Max. = 3	Road	10	10	100	70,000	10%, Med.	1
			T-6				
Aver. = 2	Road & Store	100	0	NA	NA	0%, Low	
Max. = 4	Road & Store	100	56	56	28,000	5.6%, High	1, 3
12 ft. dia. Boulder	Road & Store	1	1	100	16 million	See Text	
			T-10				
Aver. = 2	Road	100	0	NA	NA	0%, Low	
Max. = 3	Road	100	44	44	61,000	4.4%, High	1
			T-11				
Aver. = 1	Road	100	0	NA	NA	0%, Low	
Max. = 3	Road	100	33	33	390,000	3.3%, High	2
			T-12				
Aver. = 1	Road	100	0	NA	NA	0%, Low	
Max. = 2	Road	100	1	1	46,000	0.1%, Low	
			T-13				
Aver. = 1.5	Homes	100	0	NA	NA	0%, Low	
Max. = 2	Homes	100	24	24	9,000	2.4%, Low	

1. Low-energy impact fence. 2. High-energy impact fence. 3. Earth berm on lower runout slope.

potential to be initiated from the rock outcrop shown in Figure 8. A plane failure analysis, therefore, was completed to determine whether movement could occur. The potential failure discontinuity is 36°, and assuming a conservative value of 45° for the friction angle due to roughness and high confining stresses, the factor of safety is 1.16 when a dynamic load of 0.1 g is applied and a factor of safety of 1.05 if a dynamic load of 0.15 g is applied. The energy for a 12-foot diameter boulder was calculated to be 16 million ft-lb. and thereforemay produce a great deal of damage to S.R. 2 and structures downslope. However, once a boulder has failed from the outcrop, it is highly unlikely that it will retain its size as it bounces downslope, as indicated by the 3-dimensional bedrock discontinuities. It is more likely that the boulder will break apart into smaller fragments 2 feet or smaller in size. Therefore a low hazard rating was assigned to this scenario.

LOWER ICICLE CREEK VALLEY

Twelve of the seventeen project areas in the lower Icicle Creek valley were evaluated for rockfall (Table 9). Of these, three areas have potentially high levels of rockfall hazard (R2a, R11a, and R11b). Two areas (R12 and R13) have moderate levels; one area (R1) has low to moderate levels, six areas (R-2b, R-3, R4a, R-4b, R-5, and R-10) have low levels; and five areas (R-6, R-7, R-8a, R-8b, and R9) were evaluated to have no rockfall potential. Areas R11a and b shared a common pathway with R-2a, as did R-5 with R-4a and b.

Boulder size was an important factor in determining hazard level. For all of the areas the average boulder size was 2 feet. In all areas the average-size boulders did not reach any sites of concern. Two areas (R-2b and R-3) had no boulders reach sites of concern, even for maximum-size boulders.

WEDGE MOUNTAIN

One of the two project areas on Wedge Mountain was evaluated for rockfall (Table 10). The area, W-1, potentially has a medium level of rockfall hazard. The second area, W-2, was not evaluated because the field observations such as small rock size and low slope angle indicate that this area has a low hazard level. None of the average-size boulders, 2 ft in diameter, reached the site of concern, an irrigation canal. However, 48% of the maximum-size boulders (approximately 4.8% of the general boulder population) in the analysis did reach the canal.

Table 9. *Rockfall hazard assessment for lower Icicle Creek valley.*

Rock Diameter (ft)	Site Concern	Rock Number in Analysis	Rock Number Passing Analysis Point (Areas of Concern)	Percent Frequency	Average Kinetic Energy (ft-lb.)	Probability and Hazard Rating	Mitigation Alternatives (see page 41 for descriptions)
			R-1				
Aver. = 2	Homes & Road	100	0	NA	NA	0%, Low	
Max. = 4	Homes & Road	100	7	7	17,000	0.7%, Low to Medium	3
			R-2a, R-11a, and R-11b				
Aver. = 2	Home	100	0	NA	NA	0%, Low	
Max. = 4	Home	100	52	52	22,000	5.2%, High	1 or 3
			R-2b				
Aver. = 2	5 Homes & Road	100	0	NA	NA	0%, Low	
Max. = 6	5 Homes & Road	100	0	NA	NA	0%, Low	
			R-3				
Aver. = 2	3 Homes & Trailer Park	100	0	NA	NA	0%, Low	
Max. = 6	3 Homes & Trailer Park	100	0	NA	NA	0%, Low	
			R-4a and 5				
Aver. = 2	Water Plant	100	0	NA	NA	0%, Low	
Max. = 4	Water Plant	100	15	15	21,000	1.5%, Low	1
			R-4b and 5				
Aver. = 2	Road	100	0	NA	NA	0%, Low	
Max. = 4	Road	100	99	99	123,000	9.9%, Low	Sign
			R-10				
Aver. = 2	2 Homes & Road	100	0	NA	NA	0%, Low	
Max. = 3	2 Homes & Road	100	1	1	2,000	0%, Low	
			R-12				
Aver. = 2	Road	100	0	NA	NA	0%, Low	
Max. = 3	Road	100	12	12	99,000	1.2%, Medium	1
			R-13				
Average =2	Road	100	0	NA	NA	0%, Low	
Max. = 3	Road	100	2	2	23,000	0.2%, Medium	3

1. Low-energy impact fence. 2. High-energy impact fence. 3. Earth berm on lower runout slope.

Table 10. *Rockfall hazard assessment for Wedge Mountain.*

Rock Diameter (ft)	Site Concern	Rock Number in Analysis	Rock Number Passing Analysis Point (Areas of Concern)	Percent Frequency	Average Kinetic Energy (ft-lb.)	Probability and Hazard Rating	Mitigation Alternative (see p. 41 for description)
W-1							
Aver. = 2	Canal	100	0	NA	NA	0%, Low	
Max. = 4	Canal	100	48	48	283,000	4.8%, Medium	High energy impact fence.

DEBRIS FLOW ASSESSMENT

The critical question in this assessment is "Did or will the effects of the fire cause a net increase in frequency and magnitude of debris flow failures"?

Debris Flow Runout Estimates

Both the stability analyses and field data were evaluated to identify probable soil failure initiation sites within the hot burn areas. For each transect or collection of transects draining to a common channel, the first cell with a high failure probability, or the highest probability of failure within a transect with low values, was used to calculate an initial failure location and volume of material. Material stored on the slopes below the initial failure was incorporated into the flow volume. Volume estimates from field data were used where possible within measured transects. Lengths of slope between measured transects and depositional zones were assumed to transport and entrain additional debris into the flow at a volume of 86 ft^3/ft length of slope (Benda and Cundy, 1990). Downward adjustments to this number were made where field evidence indicated a lack of material. Downslope transport distances were taken from surveyed transects and calculated from topographic maps. Total estimated volumes for modeled debris flows included in this study are summarized in Tables 11 and 12. Volume estimates do not include the incorporation of woody debris in the flow mass.

Modeled failure probabilities were adjusted based on how ground conditions differed from modeled assumptions. Failure probabilities were assumed to be over estimated in areas of moderate-to-low intensity burn, as some rooting strength was assumed to remain, and in sparse stands where the pre-fire rooting strength may have been overestimated. To repeat an important point, the probability of failure reflects the failure potential during ground-saturated conditions. The frequency interval for maximum ground water conditions is unknown. The true probability of failure is the product of the failure probability during maximum ground water conditions and the probability of maximum ground water occurring.

Deposition was assumed to begin at gradients of up to 25 ° where channels become unconfined. Gradients measured on a number of accumulation surfaces or colluvial fans varied from 15 °to 25 °. As channel confinements open up, deposition is occurring on slopes of up to 25 °, including mid-slope locations.

A simple geometric model was used to estimate the length of potential runout of debris flow deposits. The depositional area was described as the sector of a circle with a conservative arc of 20 ° assuming an unobstructed flow path. Areas were calculated by dividing estimated flow volumes by an average depth of deposit of 5 ft (Beaty, 1990). The runout distance is the radius of the circle sector of area A and angle in radians (i.e., 20 ° = 0.349 rad):

$$r^2 = \frac{A}{0.5(0.349)}$$

The hazard zone is described by an arc extending the maximum runout distance in all directions below the fan apex. There exists a near-equal probability for deposition of a single event occurring in any particular direction within the fan arc. Because depositional volumes are considered to be maximum values, the probability of debris flow runout decreases with distance and decreasing slope away from the apex and with site factors such as the buttressing effect of standing timber.

Estimated depositional volumes are considered to be maximum potential volumes associated with failures initiating within the burn areas. The farthest upslope potential failure sites were used, although a failure may also initiate lower on the slope. The potential for mid-slope deposition also exists within many of the modeled flow paths but was generally not considered.

The historical inventory showed a high percentage of channelized flows depositing on the slope, contrary to the runout models we employed. This would suggest that there are differences in the assumed and actual rheology of the flows and/or the actual and assumed channel geometries below the

surveyed transects. Field evidence suggests that the debris flows constructing many of the fans were likely high in rock content. Fan deposits exposed in road cuts in Icicle Canyon are composed mainly of boulders and, considering the decomposed state of some of the granite, may be marginally clast supported (boulder or framework supported). Many of the soils and depositional areas within the channels are composed mainly of boulders that may provide additional resistance to modeled increases in pore-water pressure and flow. The fan morphology below burn areas R-1 and R-2 suggests deposition by both alluvial and debris flow processes.

Hazard Ratings and Probabilities

Several factors were evaluated to assign a level of hazard from potential debris flow events initiated within high-intensity burn areas: 1) the estimated runout length of a large magnitude event; 2) the elements at risk in the path of the potential runout; 3) the probability of failure based on the slope modeling; and, 4) site factors mitigating the delivery potential. High hazard areas were assigned in three groupings: 1) areas with a high post-burn probability of failure with potential to impact homes or public works; 2) areas that have low or moderate failure probabilities but lack site mitigation for homes, or public works; and, 3) areas with low or moderate failure probabilities that had homes well within runout zones. Medium hazards were assigned to areas based on two different groupings: 1) those with low probabilities but with elements at risk; and, 2) those with moderate or high failure probabilities with site factors mitigating debris flow deliveries. Low hazards were assigned for areas with low probabilities of post-fire failure and those where maximum estimated runout zones did not include any elements at risk.

One half of the hazard ratings fall into the medium category. The remaining ratings are equally divided between high and low hazard ratings. Medium hazard assignments in part reflect the uncertainty in the evaluation and a need for conservatism where lives and property are at risk.

Smaller-scale debris flow events may be expected to occur in the higher hazard areas within the next several years or until ground cover conditions improve and erosion rates decline. The large-magnitude events would be associated with intense or large magnitude precipitation events.

TUMWATER CANYON

Most of the Tumwater Canyon transects lack any length of fan runout areas above the highway, with the highway itself truncating fan deposits in many places. Since delivery of modeled debris flow

volumes to the highway is possible, the majority of assigned high hazard ratings are located here. Although debris flows running out to the highway in this area have been infrequent in the recent past, the loss of rooting strength and potential for accelerated debris accumulation in the steep draws may increase both the frequency and size of potential events. However, given the low frequency of debris flow types of mass movement on the east slope, snow avalanches and rockfall remain the more predictable hazards. Table 11 lists the hazard ratings for the Tumwater Canyon areas evaluated in this study.

Table 11. *Debris flow hazard assessment for Tumwater Canyon.*

Source Area	Estimated Depositional Volume (yard^3)	Estimated Length of Runout (ft)	Elements at Risk	Hazard Rating
T-1	11,000 - 15,000	600 - 680	Highway	Medium
T-2	0	0	NA	Low
T-3	11,500	600 - 740	Highway	High
T-4	9,000 - 14,500	see T-4 + T-5	Highway	Medium
T-5	6,000 - 7,000	see T-4 + T-5	Highway	Medium
T-4 + T-5	12,000 - 17,000	440 - 720	Highway	Medium
T-6, E-8	12,000	620	Highway & Homes	High
T-7, E-1 and E2	50,000	To Highway	Highway	High
T-8, E1S	36,000	a few hundred ft	Highway	Low
T-9	13,000	640	Buildings	Medium
T-10	6,000	To Highway	Highway	Low
T-11, E-4	4,000	355	Highway	High
T-11, E-5	4,000	345	Highway	High
T-12	1,700	230	Highway & Possibly Homes	Medium
T-13	3,000	310 - 400	Highway & Buildings	High

The fan below transect T-6 has been given a high hazard rating due to the buildings and homes located on the periphery of the modeled runout zone. Excavation of sediment basins or construction of berms has been suggested as potential mitigation for rockfall and may be effective for some design magnitude debris flow events. At the T-13 location, the highway has actually been excavated through

the toe of the fan deposit and may in part function in a sediment catch basin capacity buffering the hazard to the buildings, but doing nothing to decrease the hazard to traffic.

The fan below T-13 on the southern end of Tumwater Mountain has also been assigned a high hazard due to homes at risk (Figure 9). Debris flow deposits found in the channel above the fan and a debris slide appearing in the 1975 aerial photographs provide evidence of active slope movement. Also of concern at this location is the potential for additional unmitigated development on the fan. Clearing in a middle portion of the fan was in progress at the time of the field surveys.

Figure 9. *View of houses downslope from T-13. These houses are located on a previous debris flow runout deposit.*

LOWER ICICLE CREEK VALLEY

A single high hazard rating was assigned to the fan below transects R-2 and R-11, where a high probability of upslope failure was modeled, and homes and an access road are at risk (see Table 12 on page 38). The right lateral margin of the fan has also been cleared, increasing the runout potential to homes. It appears from aerial photographs that there has been some burning along the entire length of the channel above the fan.

Medium hazard ratings were assigned to the remaining fans in sections 14 and 23 in the Icicle Creek valley. Medium hazards were assigned in part because hazards were not perceived as clearly high or low from the evaluation methods used. Confidence in some modeled failure probabilities can be strengthened with better site-specific information, specifically those with modified probability ratings based on burn intensity and stand density. Hazard zonation on the medium- and high-ranked hazard fans is recommended. Hazard zonation would include a detailed inventory of fan topography, mitigating site factors, and elements at risk to assign hazard zones based on the nature and degree of hazard with distance from the fan apex.

Field evidence and reports from the resident survey indicate a potential for debris flow initiation on the slopes below and between those areas evaluated within the scope of this work. As a result, this slope hazard evaluation should be viewed as only partially complete and confined to fire-induced influences. Additional work will need to be done to ascertain pre-fire slope stability hazard conditions.

Additional areas at risk from debris-type events include the City of Leavenworth's water filtration plant located on a colluvial fan at the base of the R-5 transect. The Icicle Road truncates the fan deposit immediately upslope of the filtration plant and creates a 6-foot berm above the plant with the potential to intercept debris. The R-5 fan was assigned a medium hazard rating due to the potential for mid-slope deposition of debris potentially mobilized within the upslope burn area. The upstream water diversion structure itself does not appear to be at risk from adjacent upslope hazards. Icicle Valley above Snow Creek widens into a U-shaped glacial valley providing low-gradient slopes between the steep valley walls and the creek. The estimated runout for modeled debris flow in R-13 and R-6 would not reach Icicle Road and there are currently no buildings or capital improvements at risk in the runout zones. The fan below R-3 has similar conditions. These fans were given low hazard ratings.

Table 12. *Debris flow hazard assessment for lower Icicle Creek valley.*

Source Area	Estimated Depositional Volume ($yard^3$)	Estimated Length of Runout (ft)	Elements at Risk	Hazard Rating
R-1a	28,000	930	possibly 2 homes	Medium
R-1b	15,000	680	possibly 2 homes	Medium
R-2	23,000 - 27,000	840 - 900	homes and access road	High
R-2 and R-11a	22,000 - 36,000	820 - 1050	same as R-2	High
R-3	19,000	775	several homes	Low to Medium
R4	0	0	NA	Low
R-5	13,000	625	city filtration plant and Icicle Road	Medium
R-6 and R-12	34,000	900	none	Low
R-7	4,000	360	homes	Medium
R-8	19,000	0	homes	Low to Medium
R-9	8,500	510	homes and Icicle Road	Medium
R-10	3,500	435	1 to 2 homes and access road	Low
R-13		775	4 to 6 homes and Icicle Road	Low

WEDGE MOUNTAIN

The most vulnerable location in the Icicle Creek area is Icicle Island, where a number of homes were destroyed during the fire. The nature of the hazards here is inherent in the location, but post-fire related conditions were also evaluated for additional risk. The Icicle Island Community development appears to

be built on a relict boulder bar within the creek and the valley is confined on both sides by steep slopes. Property is subject to some inundation during flooding. There is an open irrigation canal perched immediately above the development on the right bank which received damage from rockfall during the fire, causing a breach and damage to properties downslope. Rockfall and tree-throw remain a chronic maintenance problem to the canal. Recent replacement of sections of old log flume with steel and fiberglass structures prevented additional serious damage to the canal during the wildfire. The debris flow hazard from the right bank slopes above Icicle Island is low (W-1 on Plate 2).

Mountain Home Creek appears at the contact between the granitic bedrock and Tertiary sandstone where slopes are planar and have a bench-shape morphology. The morphology in the contact zone suggests relict slumping and earth flow of an undetermined age. The mid-to-upper slope of the area suffered intense wildfire. There is private property below this slope, and the irrigation canal has an easement through it. The irrigation district also has a diversion structure for water from Mountain Home Creek. Fire damage was sustained to the canal when a large burnt pine fell into the canal east of Mountain Home Creek, ponding water that caused severe gullying of the slope and a little-used forest road below. There are currently no structures built on the fan, although it appears that seasonal structures (e.g., camping tents) have been erected. Evidence of bank slumping in the creek and minor debris flows were found in the field, but deposition is occurring in the channel in the low-gradient bench reaches. A medium hazard rating was assigned due to the irrigation canal at risk and active erosion. Erosion and drainage from the upper forest road may cause fill or crossing failures, which most likely will deposit on downslope benches. Fill pulled back from a recently abandoned forest road below the upper road is perched above the creek and may initiate a debris flow in the creek. It is recommended that the forest engineer evaluate this site for fill stability.

SNOW-AVALANCHE DAMMING ASSESSMENT

Snow avalanching does occur within the study areas as documented in resident surveys and the WSDOT Avalanche Atlas (University of Washington Geophysics Program and Department of Civil Engineering, 1975). The concern with snow avalanching is whether the avalanching has the potential to temporarily impound water in the Wenatchee River and Icicle Creek. Aerial photos show that riffles are adjacent to large alluvial and colluvial fans, indicating that material has been deposited in the streams during slope movement (rockfall and debris flows) and/or snow avalanching, and stream bedload deposition. These riffles may indicate areas where these streams have experienced temporary damming.

Correspondence with Robert Schuster, US Geological Survey, indicated that for streams of this size the height of the material to form a hazardous dam would have to be 20 to 30 feet. Assuming that damming may occur during rain-on-snow events, when the stream flow is at bankfull height, the estimated average width and depth for the Wenatchee River would be approximately 150 feet wide and 25 feet deep. For Icicle Creek Canyon the estimated bankfull width and depth would be approximately 75 feet wide and 15 feet deep. Dam material will most likely be a combination of snow, rock, and soil as indicated in the WSDOT Avalanche Atlas. To dam the Wenatchee River with a temporary dam 30 feet high, with downstream and upstream angles of 20 ° (assumed angle of repose) for the material, and a top width of 10 feet, the volume of material would be approximately 15,000 c.y. To dam the Icicle Creek within the canyon to a height of 20 feet would require approximately 4,000 c.y.

Known snow avalanches that have reached and crossed the Wenatchee River are labeled TW-6 through TW-9 in Figure 6 on page 17. Assuming that future snow avalanche events will occur from the studied areas, it is likely that potential events from the east side of the canyon may also occur, possibly from potential debris flow areas adjacent to the river: T-6 (including E-8), T-7 (including E-1 and E-2), T-11, and T-12 (see Plate 2). Damming from a combination of snow avalanches and debris flows is possible, but only from areas that have high debris flow hazard ratings and large depositional volumes (15,000 c.y. or larger). Predicted depositional volume is well over 15,000 c.y. for the identified high debris flow hazard area T-7, but not for areas T-6 and T-11 (see Table 11 on page 35). It is possible, then, that temporary damming by snow avalanche and debris flows could occur from T-7, however, a large amount of the debris flow materials will be deposited on the slopes and river banks before entering the river. Therefore, if temporary damming occurs, it will be caused primarily by snow avalanche materials from areas T-6, T-7, T-11, and T-12.

No known snow avalanches have reached Icicle Creek within the canyon. Also, no predicted debris flow runout zones reach Icicle Creek in this study. Therefore, no temporary damming of this stream is predicted.

MITIGATION ALTERNATIVES

ROCKFALL

Energy-absorbing barriers and fallout catchment zones are the primary mitigation measures for rockfall in areas where roadways and structures are in jeopardy of being damaged by rockfall (Long,

1994). Several areas were evaluated for rockfall in Tumwater Canyon, lower Icicle Creek valley, and Wedge Mountain as discussed above. However, no site-specific field mapping was completed in the runout zones because of the scope of this project (see pages i and 1). Several possible alternatives for mitigation are addressed here with the caveat that actual costs can only be obtained after site-specific geotechnical engineering field work is completed. Areas where this future work will need to be completed will be identified within the action plan in early 1995 (see pages i and 1).

Energy-absorbing Barriers

Energy-absorbing barriers include heavy wire rope netting (such as that used by defense agencies as submarine nets) supported by anchored steel supports (Long, 1994) as shown in Figure 10 (GeoBrugg, 1994). Mitigation alternatives 1 and 2 in Tables 8 and 9, and the mitigation in Table 10 are energy-absorbing fences. Fences can be installed with little disturbance to existing terrain, vegetation, or aesthetics. Based on the CRSP analysis for each potential high rockfall hazard area, fence installation will have the estimated costs listed in Table 13.

Other barriers consist of free-standing bin-type walls filled with earth, or earth-constructed berms. This type is alternative 3 in Tables 8 and 9. These barriers, however, will require disturbing the installation site by equipment excavating and pushing earth materials. Installation sites will also require adequate room for the equipment to operate, which may not be available at all sites. Cost for these earth structures will be similar to that given for fallout catchment zones.

Figure 10. *Large boulder being intercepted in energy-absorbing fence (courtesy of GeoBrugg, 1994).*

Table 13. *Conceptual designs and budget pricing for rockfall energy-absorbing fences.*

Source Area	Assumptions	Estimated Budget Price	Estimated Fence Length	Comments
T-4	60.5 ft-ton load 12 ft max. jump height	$85/linear ft.	1 fence - 675 ft. 2 fences - 1000 ft.	Two parallel fences may need to be constructed depending on site characteristics.
T-6	28.0 ft-ton load 12 ft. max. jump height	$75/linear ft.	600 ft. - 900 ft.	
T-10	55.0 ft-ton load 10 ft. max. jump height	$85/linear ft.	500 ft.	
T-11	170 ft-ton load 12 ft. max. jump height	$155/linear ft.	1 fence - 1500 ft. 2 fences - 2000 ft.	High impact ring net system. Two parallel fences may need to be constructed depending on site characteristics.
R-2 & R-11	20.0 ft-ton load 12 ft. max. jump height	$75/linear ft.	700 ft.	
R-4 & R-5	21.5 ft-ton load 12 ft. max. jump height	$75/linear ft.	1500 ft.	
R-12	57.5 ft-ton load 12 ft. max. jump height	$85/linear ft.	1200 ft.	
W-1	224.5 ft-ton load 12 ft. max. jump height	$155/linear ft.	1 fence - 700 ft. 2 fences - 1000 ft.	Two parallel fences may need to be constructed depending on site characteristics.

Note: Installation costs are estimated to be an additional 50-70% of the material costs. The estimates in this table are suitable for planning and preliminary budgeting purposes, but are not suitable for actual design costs. Additional site-specific geotechnical engineering field work must be completed before actual design costs can be determined.

Fallout Catchment Zones

Fallout catchment zones at the toe of a slope can be designed so that the depth to width ratio will be adequate to prevent a falling, rolling, or bouncing rock from going beyond the catchment zone area.

Construction of an earth berm can be included in such a design. If there is room along the slope toe to build an earth berm, and there is ample volume of accessible materials, this alternative may be very cost-effective. Estimated cost for this type of structure is approximately $10/linear foot (see cost analysis in Appendix D). This is mitigation alternative 3 in Tables 8 and 9.

Other

Another mitigation alternative is to remove the timber near potential rockfall initiation sites. This will reduce the potential for a windthrow-induced loading force from occurring. This is mitigation alternative 3 in Tables 8 and 9.

DEBRIS FLOWS

The primary mitigation measures for debris flow hazards on fans consist of identifying and mapping hazard zones, avoiding the threatened areas, installing warning systems, and predicting debris flow events (Costa, 1984; Hungr et al., 1987; Montgomery et al., 1991). Primary measures are recommended as initial solutions effective at reducing loss of life and property with the least impact on the surrounding environment.

Where development is already established or cannot be avoided, secondary measures can reduce the impacts of events. Secondary measures are intended to lower debris flow initiation potential, control the path or deposition of a debris flow, or to protect structures or modify them to withstand impact, and can be applied in the source areas, transport, and deposition zones.

A body of literature exists on both primary and secondary mitigation measures, but we will introduce only those that appear to have application to these situations. This information is offered as a basis for managers and planners to begin a planning process, and not as design standards. Consideration of these and other options can be assessed in greater detail in the planning process.

In this study, hazard ratings were assigned based on existing elements at risk; therefore, secondary mitigation measures will be discussed. However, there is still a role for primary mitigation in the form of hazard zoning recommended for future development at risk. This may not necessarily preclude development, but design standards for development should consider the potential hazards.

Perhaps the only recommended measure located in the source areas for potential events would be an early warning system in the form of remotely-sensed piezometers to measure ground water levels during

storm events. Seeding to reduce surface erosion leading to ravel and accumulations in the channels has already been done, but may need to be monitored for effectiveness due to the extreme site conditions. In the channels or transport areas, deflection or diversion structures may be appropriate to some situations to divert the flow to a less critical location.

Irrespective of additional necessary measures, maintaining standing timber in the runout area is important. The larger debris in a flow can be trapped by the trees, often damming the flow behind it. Planting trees in these areas is recommended to mitigate events in the future, but will be ineffective to address the perceived immediate post-fire increase in debris flow potential. It will be important that standing timber can be achieved through the grading and clearing permit process. Artificial barriers can also perform the same function, although at a greater cost. Catchment basins in conjunction with berms, dikes, and other structures have also been used to mitigate debris flow hazards. An estimated cost for this type of mitigation is approximately $10/linear foot (see cost analysis in Appendix D).

SNOW-AVALANCHE DAMMING

An early warning system may be the only mitigative alternative for snow-avalanche damming of the Wenatchee River and Icicle Creek.

MONITORING RECOMMENDATIONS

ROCKFALL

Two possible means of monitoring rockfall are: 1) remotely-sensed instrumentation of potential rockfall initiation sites; and 2) marking boulders in depositional areas and maintaining a seasonal photograph file of sites. The first option is the most expensive but could be used in an early-warning system, whereas the second option would be an historical cause-effect approach.

DEBRIS FLOWS

One of the main factors increasing the potential for post-fire soil failures is an increase in the amount of material in the steep draws. Erosion and accumulation pins installed in representative critical cells will enable monitoring of soil erosion and accumulation rates, in effect monitoring an increase in failure

potential. Medium hazard areas within Tumwater Canyon may be adequately monitored by instrumentation of the high hazard areas.

Monitoring climate records in conjunction with debris flow activity will probably be very useful. Researchers in California have found a relationship between large rainstorms, during high rainfall seasons, and the frequency and magnitude of landslides (Nilson et al., 1976; Ellen et al., 1990a and 1990b; and Wieczorek et al., 1990). Concurrent work was also completed in Italy that produced results similar to those of the California work. Briefly, landslides increased when the normalized storm rainfall (total storm rainfall divided by the mean annual precipitation) was greater than 0.3 in California. In Italy, similar results were obtained when the normalized storm rainfall was 0.28 to 0.38. A similar study can be completed for this project area with the results being incorporated into an early warning system.

SUMMARY STATEMENT

The essential purpose of this work was to evaluate the potential increase in frequency or magnitude of mass-wasting events due to wildfire in areas with high risk. By definition, these areas carried a pre-fire risk as well. These hazards have been well recognized by the WSDOT who have sponsored or conducted studies and inventories in the past and have maintenance and emergency plans in place. Awareness and provisions for these hazards are also needed on a city and county level to avoid an increase in the risk in these areas.

CUMULATIVE EFFECTS

A commonly accepted definition of cumulative effects (CE) can be paraphrased: "The changes to the environment caused by the interaction of natural ecosystem processes with the effects of two or more forest practices". There are, however, many non-forest management activities that affect the environment, such as those in areas containing a patchwork of different landowners within a river basin. Agriculture, residential, and urban development, and non-forest recreation areas are some examples (Koler, 1994). To give a complete summary of the post-fire CE for the Tumwater Canyon and lower Icicle Creek valley would require a continuum framework ("big picture") that is beyond the scope of this project. Therefore, the following summary is focused only on the areas studied for this project. With the exception of the Wedge Mountain and the T-7 and T-8 sites, timber harvest and road-building activities have been minimal or non-existent in the areas of steep slopes analyzed as part of this work.

Within the managed areas, additional run-off and erosion with subsequent drainage problems associated with roads are the main post-fire impacts of concern (Figure 11).

Figure 11. *Run-off and erosion with subsequent drainage problems associated with roads are the main cumulative effects for post-fire impacts at the road shown here (in T-8).*

The scope of this project included the assessment of post-fire conditions on slope stability in areas potentially at risk to mass-wasting processes, which encompasses the potential effects of the fire on the identified resources of concern. Our evaluations show a potential for increased rockfall and debris flow activity following the fire. Deposition sites and potential runout distances of these events have been estimated and areas where events may impact public resources have been identified. An increase in sediment in the streams in the finer particle ranges is to be expected. Coarse sediment evaluated within the context of this report will deposit on the slopes, in the high-gradient intermittent channels, at the base of the slope in fans, or on S.R. 2. Little coarse sediment is expected to deliver directly to fish-bearing streams. A potential exists for a few larger-magnitude mass movements in the Tumwater

Canyon to runout to the Wenatchee River, more likely from the west slopes of the canyon which were not evaluated in detail here.

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APPENDIX A

Field Data Form and Commentaries

Wenatchee NF Slope Stability Inventory Sheet

			Names:												
			Date:	Project #:											
			Other:	Transect #:											
										Surface Roughness					
		Location								Average	Estimated	Horizontal			
			Slope			Vegetation				Boulder	Roughness	Slope			Key
Cell	Begin.	End	Angle	Camera #	Photo #	Burn	Stand	Soil	Rock	Radius		Shape	Water	Remarks	
															For Burn
															1=Low
															2=Mod
															3=High
															For Stand
															1=Sparse
															2=Mod
															3=Thick

Wenatchee NF Slope Stability Inventory Sheet

		Soil Type				Rx Properties								
			Water				Slope Face			Failure Type				Key
Cell	Est. USCS	Est. Depth	Depth	Unit Wt.	Est. URC	Dip Dip Dir.	Dip Dip Dir.	Signif.	Fall	Tobble	Wedge	Slab	Remarks	
														For Soil
														Depth
														1=0 to 1'
														2=1 to 3'
														3>3'
														For Soil
														Water D.
														1=0
														2=1 to 3'
														3=Sat'd
														For Soil
														Unit Wt.
														1<70 pcf
														2=70 to
														100 pcf
														3>100 pcf
														For
														Significan.
														1=No
														2=Mod.
														3=Very

SITE SUMMARY

Site Number: R10
Other Site Description: *
Date: 9/29/94
Field Crew Members (list notetaker 1st): P.Fisher & M.Karrer

Narrative:
Burn Intensity: Moderate

Modes of Past Failure: Some signs of side slope failure into channel

Depositional Features: *

Erosion Features: Side slopes into draws are at 38-41 degrees, show signs of active erosion and slip outs

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.): Boulder field at the top of section is relatively stable, shallow slopes below will not allow for movement down slope

Expected Mode(s) of future failures: *

Anticipated likelihood of material from this source area to reach residents or road below: Slight--small amounts of debris within the channel should be stopped by channel gradient and meandering before reaching residential areas if failure does occur.

Will fire cause significant increase in probability of failure?:
No appearance of increased hazard due to fire

Other insights: *

Site Number: R10
Other Site Description: *
Date: 9/29/94
Field Crew Members (list notetaker 1st): P.Fisher & M.Karrer

Narrative:
Burn Intensity: Moderate

Modes of Past Failure: Some signs of side slope failure into channel

Depositional Features: *

Erosion Features: Side slopes into draws are at 38-41 degrees, show signs of active erosion and slip outs

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.): Boulder field at the top of section is relatively stable, shallow slopes below will not allow for movement down slope

Expected Mode(s) of future failures: *

Anticipated likelihood of material <u>from this source</u> area to reach residents or road below: Slight--small amounts of debris within the channel should be stopped by channel gradient and meandering before reaching residential areas if failure does occur.

Will fire cause significant increase in probability of failure?:
No appearance of increased hazard due to fire

Other insights: *

SITE SUMMARY

Site Number: R11A/R11B
Other Site Description: R11B is rock outcrop?
Date: 10/7/94
Field Crew Members (list notetaker 1st): BRAINSTORM

Narrative:
Burn Intensity: High

Modes of Past Failure: Rockfall, debris slides

Depositional Features: Talus in draw

Erosion Features: Debris slides, ravel

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.): Abundant outcrops above draw and adjacent to draw

Expected Mode(s) of future failures: Rockfall, debris slides

Anticipated likelihood of material from this source area to reach residents or road below: Use analysis of area R2 to judge this due to the fact the R11 joins R2 at 2600' (1500' from junction of R2/R11 to toe of slope)

Will fire cause significant increase in probability of failure?: Yes--hazard will be accessed based on R2 analysis

Other insights: *

SITE SUMMARY

Site Number: R12
Other Site Description: Lower reach (down to road)
Date: 10/7/94
Field Crew Members (list notetaker 1st): D.Jones, M.Karrer, & T.Boteilho

<u>Narrative</u>:
Burn Intensity: High in upper portion, mod in bottom half

Modes of Past Failure: None

Depositional Features: Colluvial fan, sediment traps in upper portion

Erosion Features: Gullies in fan from debris flows

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.): Boulder fields and sides of draw

Expected Mode(s) of future failures: Debris flows from above

Anticipated likelihood of material <u>from this source</u> area to reach residents or road below: Low, long flat (200' of 14% slope)

Will fire cause significant increase in probability of failure?: Doubtful, possibly when mobilized by failures from above (rare)

Other insights: *

SITE SUMMARY

Site Number: R2 Lower Reach
Other Site Description: *
Date: 10/8/94
Field Crew Members (list notetaker 1st): D.Jones, M.Karrer, & T.Boteilho

<u>Narrative</u>:
Burn Intensity: Moderate

Modes of Past Failure: *

Depositional Features: Colluvial fan

Erosion Features: Draws and gullies eroded in fan by debris flows from above

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.): *

Expected Mode(s) of future failures: Debris flows will move material on to lower near flat areas

Anticipated likelihood of material <u>from this source</u> area to reach residents or road below: *

Will fire cause significant increase in probability of failure?: *

Other insights: *

SITE SUMMARY

Site Number: R5
Other Site Description: *
Date: *
Field Crew Members (list notetaker 1st): BRAINSTORM

Narrative:
Burn Intensity: High intensity--mid slope to ridge top

Modes of Past Failure: Appears heavy maple in low draw. Rockfall in upper region/debris slides in lower channel

Depositional Features: Talus draw in lower reaches

Erosion Features: Surface ravel

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.):
Ridges adjacent to draw

Expected Mode(s) of future failures: Debris flow in draw

Anticipated likelihood of material from this source area to reach residents or road below: Moderate to high probability of debris (bottom channel needs to be walked and mapped) due to residences below and road

Will fire cause significant increase in probability of failure?: Yes, due to high incidence of debris slides in adjacent sites prior to burn

Other insights: If it appears from above recon that material may reach roads or residences, further analysis (site profile, etc.,) will be needed

SITE SUMMARY

Site Number: R6
Other Site Description: *
Date: 10/7/94
Field Crew Members (list notetaker 1st): BRAINSTORM

Narrative:
Burn Intensity: Mod - High intensity --mid to ridge top

Modes of Past Failure: Rock fall

Depositional Features: Within burn--talus in draws

Erosion Features: N/A

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.): Broad areas of low outcrops

Expected Mode(s) of future failures: Rock fall (continued)

Anticipated likelihood of material from this source area to reach residents or road below: Low probability of reaching areas below due to high angle of entry into main draw (~90 degrees) in R12.

Will fire cause significant increase in probability of failure?: No

Other insights: *

SITE SUMMARY

Site Number: T1
Other Site Description: Tumwater Canyon, East Ridge, at flume bridge
Date: 10/13/94
Field Crew Members (list notetaker 1st): M.Karrer, T.Boteilho, & K.Anderson

Narrative:
Burn Intensity: High

Modes of Past Failure: Rock falls, topples

Depositional Features: Small <25'dia catch basins

Erosion Features: Sheet wash into gullies, hydrophobic soils allow increase of volume into gullies moving larger material, granites spalling sheets post fire, tree roots wedging large material on outcrops cliff sources--roots burned toppling snags. Snags show impact scars from recent rock impact.

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.):
Large outcrop walls--see photos and notes. Boulder fields accumulate in slope changes

Expected Mode(s) of future failures: Snags falling could induce large (3 dia - 6 dia) boulder movement

Anticipated likelihood of material from this source area to reach residents or road below: Large talus field 2000' above road will act as buttress to rocks falling onto road. Large boulders ? have slight likelihood to reach road although the boulder field/talus field above road is comprised of large material.

Will fire cause significant increase in probability of failure?:
Not significant increase

Other insights: Hydrophobic soils, dry ravelling present, large raptor rest on cliff outcrop, North side of drainage ~3,000' above road. Large pronounced joint set.

Dip Dir	Dip	Dip Dir	Dip
116	88	62	89
134	64	180	77
N87W	88	280	68
180	88	10	18
		271	71
		0	82

SITE SUMMARY

Site Number: T10
Other Site Description: Burn above mouth of Tumwater Canyon
Date: 10/13/94
Field Crew Members (list notetaker 1st): M.Gowan, D.Jones, & L.Cartner

Narrative:
Burn Intensity: High intensity burn throughout entire transect

Modes of Past Failure: Rock fall, rock topple

Depositional Features: Boulder piles below outcrop areas; loose talus toward bottom of burn

Erosion Features: Sheetwash

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.):
Outcrops, rock walls, boulder piles, loose boulders

Expected Mode(s) of future failures: Continued rockfall from bedrock walls; Boulders loosened by tree fall. Boulders on the loose due to soil mobilization (sheetwash/debris flow processes where deep enough).

Anticipated likelihood of material from this source area to reach residents or road below: Excellent possibility of delivery to downslope areas. Bottom of burn on slightly shallower slopes (~32 degrees) forming a small catchment, but rest of runout is steep and rocky--and directs material toward the road.

Will fire cause significant increase in probability of failure?: Yes, because downed trees (or falling trees) can mobilize boulder-sized (>3' dia) particles. Soils will also be eroding from under boulder accumulation zones.

Other insights: Very shallow soils (<1') over decomposed granite on slopes >40 degrees. Rock chutes between rock walls are funneling material through particularly steep sections. Seeps (2) and a spring observed about 100' up from bottom of burn.

SITE SUMMARY

Site Number: T11
Other Site Description: *
Date: 10/7/94
Field Crew Members (list notetaker 1st): BRAINSTORM

<u>Narrative</u>:
Burn Intensity: Mod - High

Modes of Past Failure: Rockfall - freeze thaw

Depositional Features: *

Erosion Features: Ravel, debris slide

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.):
Outcrops within burn area

Expected Mode(s) of future failures: Rockfall

Anticipated likelihood of material <u>from this source</u> area to reach residents or road below: Very good, long history of rockfall based WADOT Survey

Will fire cause significant increase in probability of failure?:
Needs to be accessed

Other insights: *

SITE SUMMARY

Site Number: T12
Other Site Description: Assess based on T6 analysis DCJ
--Assess based on T6, long history of rockfall based on WADOT report PEG
Date: *
Field Crew Members (list notetaker 1st): *

<u>Narrative</u>:
Burn Intensity: *

Modes of Past Failure: *

Depositional Features: *

Erosion Features: *

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.): *

Expected Mode(s) of future failures: *

Anticipated likelihood of material <u>from this source</u> area to reach residents or road below: *

Will fire cause significant increase in probability of failure?: *

Other insights: *

SITE SUMMARY

Site Number: T1
Other Site Description: Bottom 2000' of drainage below burn T1 down to road
Date: 10/11/94
Field Crew Members (list notetaker 1st): L.Cartner, D.Jones, T.Boteilho, & M.Karrer

Narrative:
Burn Intensity: Moderate to high from 0-800'
Low from 800-2000' (road)
Modes of Past Failure: Debris flows lower by road
Rock falls in upper transect

Depositional Features: Boulders in drainage creating stair stepping dam effects Debris flow at lower end which have subsequently had drainage cut through

Erosion Features: Freshly broken rocks indicate rock falls but no major erosion has occurred recently

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.): Boulders on side slopes. Very little outcrops indicate source is higher than transect. Small rock dam at toe could contributed to road but not high problem. Ridge to North in cell 2 has outcrop
Expected Mode(s) of future failures: Rock falls and minor debris flows.

Anticipated likelihood of material from this source area to reach residents or road below: Stair stepping dams of boulders catch falling rocks also less steep toe of drainage and curve in direction of drainage could also be a deposition zone. May have some reach road.

Will fire cause significant increase in probability of failure?: Yes, boulders will be falling down to draw

Other insights: *

SITE SUMMARY

Site Number: T3
Other Site Description: Line 1
Date: 9/30/94
Field Crew Members (list notetaker 1st): P.Fisher, B.Shelmerdine, & M.Skinner

<u>Narrative</u>:
Burn Intensity: Moderate @ very top to high intensity in main section. Lower channel @ low to mod. burn.
Modes of Past Failure:
High ravel rates, rockfall, toppling, etc... of erosive soils

Depositional Features: Channel acts as an accum. zone in several places from top to bottom

Erosion Features: Active surf erosion occurring in the soil slopes

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.):
Outcrop @ top of section along w/ outcrops adj. to channel past the accum. zone down slope.

Expected Mode(s) of future failures: Rock fall from outcrops, surf erosion 9/or debris slides from side slopes adjacent to channel

Anticipated likelihood of material <u>from this source</u> area to reach residents or road below: Due to shallow slopes @ base a high roughness values, unlikey that rockfall would reach the road. If the energy was great enough debris material might make it to the road (under typical conditions this probably is very little)

Will fire cause significant increase in probability of failure?:
Increased the probability of debris slides.

Other insights: Much of the boulders which might cause a danger of rockfall are below the burn areas adjacent to the stream.

SITE SUMMARY

Site Number: T3
Other Site Description: Lines 3A (Rock Fall Source) 3B (Rock Fall Accum. Chute)
Date: 9/28/94 (Base Tres
into T3 Num 2)
Field Crew Members (list notetaker 1st): P.Jones & M.Karrer

<u>Narrative</u>:
Burn Intensity: High--Throughout survey area

Modes of Past Failure: Topple, fall, roll in source area (3ft) along with high ravel rates of digi soils

Depositional Features: T3/3B is along chute that acts as zone of accumulation

Erosion Features: Extreme burn has created very high ravel of surficial soils

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.): 3A has high cliffs that produces boulders

Expected Mode(s) of future failures:
--Continued topple/fall/roll from cliffs
--Expect debris slides on steep, intensely burned side slope

Anticipated likelihood of material <u>from this source</u> area to reach residents or road below:
--Situated @ hilltop...very little chance of reaching road
--Accumulation of boulders in chute indicates they don't move far down channel

Will fire cause significant increase in probability of failure?:
Fairly high chance of initiating debris slides (probably up to 3' thick soil mass failure)

Other insights: *

SITE SUMMARY

Site Number: T4
Other Site Description: Above Tumwater Canyon Dam, Sec 34, Tumwater Botanical Area
Date: 10/12/94
Field Crew Members (list notetaker 1st): M.Gowan, M.Karrer, K.Anderson

<u>Narrative</u>:
Burn Intensity: Mod/low in upper region of unit, middle of unit high intensity, grades downslope into lower burn
Modes of Past Failure: Rock falls, topples

Depositional Features: Rock falls rolled into small (<30' wide) catch basins

Erosion Features: Steep gullies (~30 degree slope)

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.): Outcrops

Expected Mode(s) of future failures: Rockfalls and topples. Possible boulder rolling once initial soil/topsoil erosion begins. In high intense burn areas, stands are thick and if they fall could trigger boulder downslope movement.

Anticipated likelihood of material <u>from this source</u> area to reach residents or road below: Boulders with >2' radius have good likelihood to reach road. Could also trigger larger movements.

Will fire cause significant increase in probability of failure?:
Not significant. Debris flows have potential to build material up at confluence of T4 and T5 to point of large flows moving down in 2-3 years. Toppling snags could trigger loose boulders to begin movement. Loose soils could move due to loss of vegetation if precipitation was heavy.

Other insights: Top of burn is boulder source area, loose soils throughout unit. Outcrop walls provide source boulder material. Steep (45 degree)< falls over outcrops in gullies from end of burn downslope to road highway #2.

SITE SUMMARY

Site Number: T4 S
Other Site Description: Burns South of T4, not surveyed but looked at
Date: 10/12/94 (labeled T4.1, T4.2 from N to S)
Field Crew Members (list notetaker 1st): M.Karrer

<u>Narrative</u>:
Burn Intensity: High burn intensity

Modes of Past Failure: Rock falls in both T4.1 and T4.2, T4.2 has deeply incised channel

Depositional Features: Rock fall in small catch basins

Erosion Features: Steep gullies with incised channels

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.):
Outcrops and boulder fields

Expected Mode(s) of future failures: For T4.1: Rock falls and topples, soil and top soil erosion with possibility of entrained boulders.
For T4.2: Rock falls and topples, soil and top soil erosion, gully deep and incised may be a better conduit for debris flow than slopes of T4.1.

Anticipated likelihood of material <u>from this source</u> area to reach residents or road below: T4.1 is essentially a planar slope with a mild gully system in burn area. Gully was not walked to road so potential to hit road is unknown.

T4.2: Very narrow and steep gully and obliques show channel continuing straight through cliff ? to road. Potential for large boulders hitting road is slim due to roughness (other boulders) but debris flows would likely hit road.

Will fire cause significant increase in probability of failure?: Rockfall increase is minimal, but the possibility of snags disloging boulders exist. Vegetation loss will increase soil erosion and transport in short term, accumulation of eroded soil in small catch basins may provide material for larger debris flows in 2-3 years.

Other insights: Top of burn is source area, loose soils throughout burn. Slope angles are min of 30 degrees

SITE SUMMARY

Site Number: T4/T5
Other Site Description: *
Date: 10/7/94
Field Crew Members (list notetaker 1st): Brainstorm*

Narrative:
Burn Intensity: High intensity

Modes of Past Failure: Historical failures/talus slopes at roadway

Depositional Features: *

Erosion Features: Debris slides, talus slopes, channelized

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.): Outcrops

Expected Mode(s) of future failures: Debris slides channelized, high rates of soil erosion in burn area

Anticipated likelihood of material from this source area to reach residents or road below:
Moderate to high probability will reach the road due to steep slopes and burn out of organic debris dams.

Will fire cause significant increase in probability of failure?:
Will be increased rockfall and debris reaching the road due to the burn out of organic debris dams. (and general lack of veg. in burn area)

Other insights: *Needs to be analyzed. Look at least one or (2) of the 4-5 areas of high intensity burn out

SITE SUMMARY

Site Number: T5
Other Site Description: Starting at top of burn at 3800' elevation
Date: 10/12/94
Field Crew Members (list notetaker 1st): L.Cartner & T.Boteilho

Narrative:
Burn Intensity: Top of burn was high for about 500'. Middle was moderate and lower was low. Top had large snags down.
Modes of Past Failure: Rock falls from outcrops just above burn (@100-300') and 660' into transect. Thin sheet soil failures on sides of draw due to thin soils over harder decomposed rock.

Depositional Features: Large boulders (at 10-20') to medium (2-4') boulders accumulated in narrow drainage behind others as a dam effect and general scattering along drainage
Erosion Features:
Soil erosion over decomposed granodinite.

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.):
Outcrops at top of burn is major soucre with others sat 660' into transect. Side slopes had possibly 20% boulders to soil and is not a major source.

Expected Mode(s) of future failures: 1) Soil sheet flows with minor boulders throughout, jointing directions is not a major problem since strike goes into slope. 2) However, rocks will be breaking off and falling. 3) Boulders scattered will be source from side slopes ranging from 1-3" generally.

Anticipated likelihood of material <u>from this source</u> area to reach residents or road below: Major source at tp appears to be depositing within cell 1 and 2, at fork in drainage beyond bottom drainage does not have as many boulders as moderate possibility to reach road mainly because of and steepens above and the distance to the road.

Will fire cause significant increase in probability of failure?:
Outcrop sources does not appear

Other insights: *

SITE SUMMARY

Site Number: T5
Other Site Description: Starting at top of burn at 3800' elevation
Date: 10/12/94
Field Crew Members (list notetaker 1st): L.Cartner & T.Boteilho

<u>Narrative</u>:
Burn Intensity: Top of burn was high for about 500'. Middle was moderate and lower was low. Top had large snags down.
Modes of Past Failure: Rock falls from outcrops just above (@100-300') and 600' into transect. Thin sheet soil failures on sides of draw due to thin soils over harder decomposed rock.

Depositional Features: Large boulders (@10-20') to medium (2-4') boulders accumulated in narrow drainage behind others as a dam effect and general scattering along drainage
Erosion Features: Soil erosion over decomposed granodinite.

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.): Outcrops at top of burn is major source with others at 660' into transect. Side slopes had possibly 20% boulders to soil and is not a major source.

Expected Mode(s) of future failures: 1) Soil sheet flows with minor boulders throughout, jointing directions is not a major problem since strike goes into slope, 2) however, rocks will be breaking off and falling 3) Boulders scattered will be source from side slopes ranging from 1-3' generally.

Anticipated likelihood of material <u>from this source</u> area to reach residents or road below: Major source at top appears to be depositing within cell 1 and 2, at fork in drainage beyond bottom drainage does not have as many boulders and steepens. Moderate possibility to reach road mainly because of above and the distance to the road.

Will fire cause significant increase in probability of failure?: Outcrop sources does not appear to be affected. Boulders on side slopes will most likely fall but most likely will not be significant. High probability for soil sheet flow failure.

Other insights: High in burn trees will continue to fall down. Many have roots burned out and have little strength. Dry drainage until it reaches fork where at 0.5 gpm flows.

SITE SUMMARY

Site Number: T6
Other Site Description: Cells 1 and 2 bottom of drainage to road
Date: 10/11/94
Field Crew Members (list notetaker 1st): L.Cartner, D.Jones, T.Boteilho, & M.Karrer

<u>**Narrative:**</u>
Burn Intensity: High, duff and veg. burned some trees still alive

Modes of Past Failure: Rock falls and debris flows at bottom possibly

Depositional Features: Boulder fields in drainage

Erosion Features: Some recent (post fire) soil slides, but minor 20-30' long in cell 2.

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.): Outcrops in cell 1 are sources. Jointing appears to have controlled boulder failures after the fire.

Expected Mode(s) of future failures: Rock falls off of outcrops and slopes. Shallow soil failures on side slopes.

Anticipated likelihood of material <u>from this source</u> area to reach residents or road below: Many boulder dams in drainage appear to catch many rocks falling (boulders reduced in cell 2 down slope), however, there's always a chance of reaching to road. Trees are not dense enough to stop rocks generally.

Will fire cause significant increase in probability of failure?: Yes, there's slaking of rocks and many nicks in boulders as evidence of rock falls already.

Other insights: Cell 2 towards bottom gets slightly dense but not with stout trees to stop boulders.

SITE SUMMARY

Site Number: T6
Other Site Description: Line 1
Date: 9/29/94
Field Crew Members (list notetaker 1st): P.Fisher, B.Shelmerdine, & M.Skinner

Narrative:

Burn Intensity: High intensity

Modes of Past Failure: Rockfall, active surf. erosion (raveling)

Depositional Features: A few depositional areas within channel of soil and Rx from side slopes

Erosion Features: Active surf. erosion (raveling)

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.):
Boulder fields along slope

Expected Mode(s) of future failures: Surf erosion (raveling), failure of accumulation zone at end of transect, rilling within channel

Anticipated likelihood of material from this source area to reach residents or road below: Low probability due to location on the slope--further investigation of down slope angles and run out zone needed

Will fire cause significant increase in probability of failure?: Some boulders against trees and accumulation at end of transect is against burned trees, depends on lower slope and how far material could travel.

Other insights: *

SITE SUMMARY

Site Number: T6 Lines 1A & 1B
Other Site Description: Southernmost transect in T-6, Line 1B is offset 400' to
Date: 9/28/94 South from 1A.
Field Crew Members (list notetaker 1st): M.Long, P.Jones, & M.Karrer

Narrative:
Burn Intensity: High/Intense

Modes of Past Failure: Predominately ravel of steeper dig. slopes -- in 1A
Some boulder roll in 1A, abundant in 1B

Depositional Features: Talus, boulders

Erosion Features:

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.):
Cells 3-5 in line 1B

Expected Mode(s) of future failures: Roll, topple

Anticipated likelihood of material from this source area to reach residents or road below: Accumulation of talus in cell 7 indicates that rock doesn't move to far from cells 3-5. Low prob. of debris flows in channel.

Will fire cause significant increase in probability of failure?: Some boulders in 1A are against burned trees

Other insights: *

SITE SUMMARY

Site Number: T6 Line 3
Other Site Description: Northernmost line along edge of burn
Date: 9/28/94
Field Crew Members (list notetaker 1st): M.Gowan, D.Reich, & M.Ballerine

Narrative:
Burn Intensity: Low out top, increases in mid section from mod. to high

Modes of Past Failure: Rockfall from outcrop areas, debris slide (old) has headwall near road landing

Depositional Features: Loose scree remaining in old debris slide, ravel.

Erosion Features: Sheetwash in old headwall area

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.): Outcrop to North of line (approx 350′ down from point of beginning for transect, and 100′ over)

Expected Mode(s) of future failures: Rockfall from outcrop (discontinuity data collected)

Anticipated likelihood of material from this source area to reach residents or road below: Low, unless large (>6′dia.) blocks fail and are mobilized downslope
Some rill and gully erosion will likely result

Will fire cause significant increase in probability of failure?:
No, other than soil erosion.

Other insights: Transect ends PRIOR to confluence of channels and/or lines 1A, 1B, 1C -- so difficult to judge downslope runout potential. Total transect length: ~1200ft.
See also transect done on rock ridge for CRIS P. (parallels cell 4 & 5)

SITE SUMMARY

Site Number: T7/T8
Other Site Description:
Date: 10/1/94
Field Crew Members (list notetaker 1st): M.Karrer & M.Skinner

<u>Narrative</u>:
Burn Intensity: High to 1334 ft. Med to low from 1334 --> 3511

Modes of Past Failure: Debris flow, rotational slump

Depositional Features: Debris fans, slump blocks, debris accumulation zone

Erosion Features: Gullying, ravelling, rill and slope failure

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.): No RX fall sources to speak of

Expected Mode(s) of future failures: Slump and debris flow

Anticipated likelihood of material <u>from this source</u> area to reach residents or road below: Moderate possibility of debris flow entering main channel and making it to road. Gradient at confluence of sub-basins is 6 degrees with an increase to >8 degrees past confluence in main channel. Confluence < is 40 degrees (angle will be <u>greater</u> if taken from tangent as per benda)

Will fire cause significant increase in probability of failure?: Historical evidence of slope failure due primarily to logging. Massive slope failure may see a moderate increase due to fire, but slope failure has been occurring in basin for >50 years.

Other insights: *

SITE SUMMARY

Site Number: T8 Road System
Other Site Description: Upper-most road of the three (at top of watershed)
Date: 10/6/94 Photos on C-9
Field Crew Members (list notetaker 1st): M.Gowan & M.Karrer

Narrative:
Burn Intensity: Low to moderate and mostly downslope from the road

Modes of Past Failure:
--Cutslope failures at sta. 12+00, and between sta 9+00 to 10+00.
--Sloughing also common on cutslope between rock outcrops in segment sta 8+00 to 11+00.

Depositional Features: None observed, other than some scree on slopes below sidecast, and a few scattered boulders.

Erosion Features:
--Sloughing, rill and gully erosion, and sheetwash on cutslopes.
--Minor gullying of fill slopes in places where root wads were burned completely.

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.): None, really. Some weathering of rock from outcrop areas along cutslopes

Expected Mode(s) of future failures:
--Cutslope failure will continue on some sections where burned vegetation can no longer anchor thin soils overlying bedrock.
--Fillslope failures possible in a few areas where sidecast will be undercut following treefall/windthrow. Incipient tension cracks observed.

Anticipated likelihood of material <u>from this source</u> area to reach residents or road below:
--Very low to nonexistent
--Cutslope failures appear localized and are delivering small volumes (a few cubic years) of material to road.
--Transport of Fill slope failures would likely be limited to ~50-100' distance due to slope gradients and catchments below road.

Will fire cause significant increase in probability of failure?:
--Yes, for sidecast, but failure should be localized.
--No, for cutslopes.

Other insights: Overall, road is in very good shape. Can expect sidecast to collapse in places where root wads burned out, and some piping. Only section with significant potential for fill failure is from sta 0+00 to 4+00, where material is piled behind trees and sidecast slopes are steep...and mobilization to lower roads is possible.

SITE SUMMARY

Site Number: T9
Other Site Description: *
Date: 10/7/94
Field Crew Members (list notetaker 1st): BRAINSTORM

<u>Narrative</u>:
Burn Intensity: High intensity

Modes of Past Failure: Rock roll

Depositional Features: *

Erosion Features: Ravel, debris slide

Rock Fall Sources (outcrops, talus slopes, boulder field, etc.):
Crest of peak outcrops at top of burn and along ridges adjacent to draw

Expected Mode(s) of future failures: Debris slide, rockfall

Anticipated likelihood of material <u>from this source</u> area to reach residents or road below: Not likely due to catchment at 2400-2600' also slopes significantly decrease below 2400'. 500' of run out below slope

Will fire cause significant increase in probability of failure?: No

Other insights: *

APPENDIX B

Soil Laboratory Test Results

PROJECT WENATCHEE FOREST WENATCHEE ROAD NO. 113

Field No. Lab No. 11-94-4

WILLAMETTE NATIONAL FOREST MATERIALS LABORATORY
1509 W 1st ST., EUGENE, OR. 97402 (503)465-6845

WENATCHEE NO. 11-94-004 REPORT OF LABORATORY TEST RESULTS

Sampled From	Depth	Location: M.P.	Sta. 52+00
		T. S., R. E., SEC , 1/4, 1/4	
Type of Material FILL	Sampled By	Date Sampled 10-18-94	Report To M.LONG
Applicable Spec.	Title	Date Recieved 11-21-94	Address SO
Description of Material			Rock Source

	Test	Result	Sieve Size	% Passing Test	% Passing Spec
X	Liquid Limit AASHTO T89	18	Sieve Analysis (AASHTO T-11,27)		
X	Plastic Index AASHTO T90	NP	Sieve Size	Test	Spec
X	Classification: AASHTO M145	A-2-4(0)			
X	Unified	SMu			
	Moisture Density Test				
	AASHTO T99 Method				
	Maximum Dry Density pcf				
	Optimum Moisture, %				
	California Bearing Soaked 95%				
	Ratio AASHTO T193 Soaked 90%		3/4"	100	
	Opt Moisture (Unsoaked) 95%		1/2	99	
	Sand Equivalent As Recieved		3/8	99	
	AASHTO T176 Manufactured		NO. 4	97	
	LAR AASHTO T-96 Grading " "		10	94	
	Durability Course		40	72	
	AASHTO T210 Fine		100	47	
	Oregon Air H		200	33.4	
	Degradation P20				
	Spec.Gravity AASHTO T-85(Bulk)				
	(SSD)				
	(Apparent)				
	Absorption % AASHTO T-85				
	Specific Gravity AASHTO T-100				
	Unit Wt. Loose pcf				
	AASHTO T-19 Dry Rodded				
X	Field Moisture Content %	1.0			

% Moisture at Time of Penetration for Soaked CBR at 95% of Max. Dens. =
% Moisture at Time of Penetration for Soaked CBR at 90% of Max. Dens. =

REMARKS:

X-SECTION
WOODY MATERIAL

Signed BARRY A WOMACK Date 12-5-94

PROJECT WENATCHEE FOREST WENATCHEE ROAD NO.

Field No. Lab No. 11-94-5

WILLAMETTE NATIONAL FOREST MATERIALS LABORATORY
1509 W 1st ST., EUGENE, OR. 97402 (503)465-6845

WENATCHEE NO. 11-94-005 REPORT OF LABORATORY TEST RESULTS

Sampled From SITE 1-R9	Depth 1.0'-2.5'	Location: M.P. Sta. T. S., R. E., SEC , 1/4, 1/4	
Type of Material	Sampled By BILL S.	Date Sampled 9-30-94	Report To M.LONG
Applicable Spec.	Title	Date Recieved 11-21-94	Address SO
Description of Material			Rock Source

	Test	Result	Sieve Analysis (AASHTO T-11,27) Sieve Size	% Passing Test	% Passing Spec
X	Liquid Limit AASHTO T89	NP			
X	Plastic Index AASHTO T90	NP			
X	Classification: AASHTO M145	A-1-b(0)			
X	Unified	SMd			
	Moisture Density Test				
	AASHTO T99 Method				
	Maximum Dry Density pcf				
	Optimum Moisture, %				
	California Bearing Soaked 95%				
	Ratio AASHTO T193 Soaked 90%		3/4"	100	
	Opt Moisture (Unsoaked) 95%		1/2	99	
	Sand Equivalent As Recieved		3/8	98	
	AASHTO T176 Manufactured		NO. 4	96	
	LAR AASHTO T-96 Grading " "		10	79	
	Durability Course		40	42	
	AASHTO T210 Fine		100	24	
	Oregon Air H		200	14.8	
	Degradation P20				
	Spec.Gravity AASHTO T-85(Bulk)				
	(SSD)				
	(Apparent)				
	Absorption % AASHTO T-85				
	Specific Gravity AASHTO T-100				
	Unit Wt. Loose pcf				
	AASHTO T-19 Dry Rodded				
X	Field Moisture Content %	1.0			

% Moisture at Time of Penetration for Soaked CBR at 95% of Max. Dens. =
% Moisture at Time of Penetration for Soaked CBR at 90% of Max. Dens. =

REMARKS:

SOFT, DECOMPOSING

Signed BARRY A WOMACK Date 12-5-94

PROJECT WENATCHEE FOREST WENATCHEE ROAD NO.

Field No. Lab No. 11-94-6

WILLAMETTE NATIONAL FOREST MATERIALS LABORATORY
1509 W 1st ST., EUGENE, OR. 97402 (503)465-6845

WENATCHEE NO. 11-94-006 REPORT OF LABORATORY TEST RESULTS

Sampled From	Depth	Location: M.P. Sta. T. S., R. E., SEC , 1/4, 1/4	
Type of Material SOIL	Sampled By	Date Sampled 10-18-94	Report To M.LONG
Applicable Spec.	Title	Date Recieved 11-21-94	Address SO
Description of Material			Rock Source

	Test	Result	Sieve Analysis (AASHTO T-11,27) Sieve Size	% Passing Test	% Passing Spec
X	Liquid Limit AASHTO T89	26			
X	Plastic Index AASHTO T90	NP			
X	Classification: AASHTO M145	A-4(0)			
X	Unified	SMu			
	Moisture Density Test				
	AASHTO T99 Method				
	Maximum Dry Density pcf				
	Optimum Moisture, %				
	California Bearing Soaked 95%		1"	100	
	Ratio AASHTO T193 Soaked 90%		3/4	93	
	Opt Moisture (Unsoaked) 95%		1/2	93	
	Sand Equivalent As Recieved		3/8	93	
	AASHTO T176 Manufactured		NO. 4	89	
	LAR AASHTO T-96 Grading " "		10	85	
	Durability Course		40	71	
	AASHTO T210 Fine		100	50	
	Oregon Air H		200	35.8	
	Degradation P20				
	Spec.Gravity AASHTO T-85(Bulk)				
	(SSD)				
	(Apparent)				
	Absorption % AASHTO T-85				
	Specific Gravity AASHTO T-100				
	Unit Wt. Loose pcf				
	AASHTO T-19 Dry Rodded				
X	Field Moisture Content %	8.3			

% Moisture at Time of Penetration for Soaked CBR at 95% of Max. Dens. =
% Moisture at Time of Penetration for Soaked CBR at 90% of Max. Dens. =

REMARKS:

T-12, CELL #1

Signed BARRY A WOMACK Date 12-5-94

PROJECT WENATCHEE FOREST WENATCHEE ROAD NO.

Field No. Lab No. 11-94-7

WILLAMETTE NATIONAL FOREST MATERIALS LABORATORY
1509 W 1st ST., EUGENE, OR. 97402 (503)465-6845

WENATCHEE NO. 11-94-007 REPORT OF LABORATORY TEST RESULTS

Sampled From	Depth	Location: M.P. Sta. 13+50 T. S., R. E., SEC , 1/4, 1/4	
Type of Material FILL	Sampled By	Date Sampled 10-11-94	Report To M.LONG
Applicable Spec.	Title	Date Recieved 11-21-94	Address SO
Description of Material			Rock Source

			Sieve Analysis (AASHTO T-11,27)		
				% Passing	
X	Liquid Limit AASHTO T89	31			
X	Plastic Index AASHTO T90	4	Sieve Size	Test	Spec
X	Classification: AASHTO M145	A-2-4(0)			
X	Unified	GMu			
	Moisture Density Test				
	AASHTO T99 Method				
	Maximum Dry Density pcf		2"	100	
	Optimum Moisture, %		1 1/2	95	
	California Bearing Soaked 95%		1	91	
	Ratio AASHTO T193 Soaked 90%		3/4	86	
	Opt Moisture (Unsoaked) 95%		1/2	80	
	Sand Equivalent As Recieved		3/8	75	
	AASHTO T176 Manufactured		NO. 4	64	
	LAR AASHTO T-96 Grading " "		10	54	
	Durability Course		40	41	
	AASHTO T210 Fine		100	32	
	Oregon Air H		200	25.9	
	Degradation P20				
	Spec.Gravity AASHTO T-85(Bulk)				
	(SSD)				
	(Apparent)				
	Absorption % AASHTO T-85				
	Specific Gravity AASHTO T-100				
	Unit Wt. Loose pcf				
	AASHTO T-19 Dry Rodded				
X	Field Moisture Content %	5.4			

% Moisture at Time of Penetration for Soaked CBR at 95% of Max. Dens. =
% Moisture at Time of Penetration for Soaked CBR at 90% of Max. Dens. =

REMARKS:

LOWER ROAD T-8

Signed BARRY A WOMACK Date 12-5-94

APPENDIX C

Rockfall Analyses

BRIEF EXPLANATION OF DIP VECTOR STEREONET INTERPRETATION

Dip vector stereonet projection is a tool that may be used to represent the orientations of discontinuities in a rockmass with respect to existing or proposed rock slopes for the purpose of identifying potential plane, wedge, and toppling failures.

Potential Plane Failures:

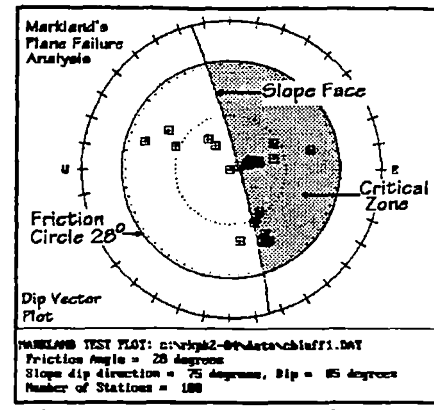


Figure 1. Potential plane failures.

The stereonet in Figure 1 contains 48 discontinuities plotted as small squares. The dip value of each is indicated by radial position. That is, points on the outer circle have a zero dip (horizontal surfaces), 30° dip is represented by the first dotted circle, 60° dip is represented by the inner dotted circle, and 90° dip (vertical surfaces) is represented by the stereonet center. Dip direction is indicated by the compass direction of points referenced to the stereonet center. Points falling within the shaded moon-shaped area are steeper than the friction angle yet less steep than the slope face hence they daylight and are potential failure surfaces. Safety factors should be calculated for those points. (Note: points dipping most directly out of the slope face, as in the "critical zone central region" of Figure 3 below, are the most likely plane failures.)

Potential Wedge Failures:

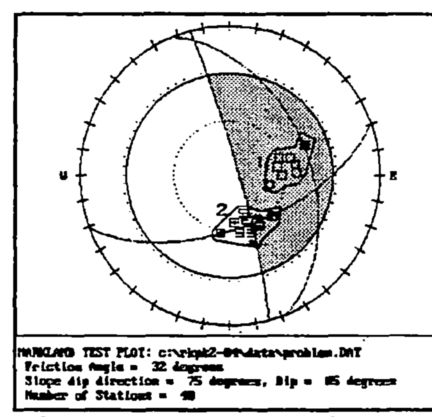


Figure 2. Potential wedge failure.

Great circles may be drawn through clusters of points or individual points to represent those dipping planes. If any intersections between these great circles fall within the moon-shaped shaded area, as in Figure 2, wedge failures from the rock mass are possible. Wedge failure safety factors should be calculated.

Potential Toppling Failures:

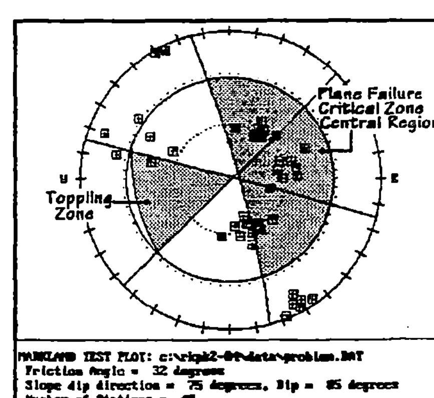
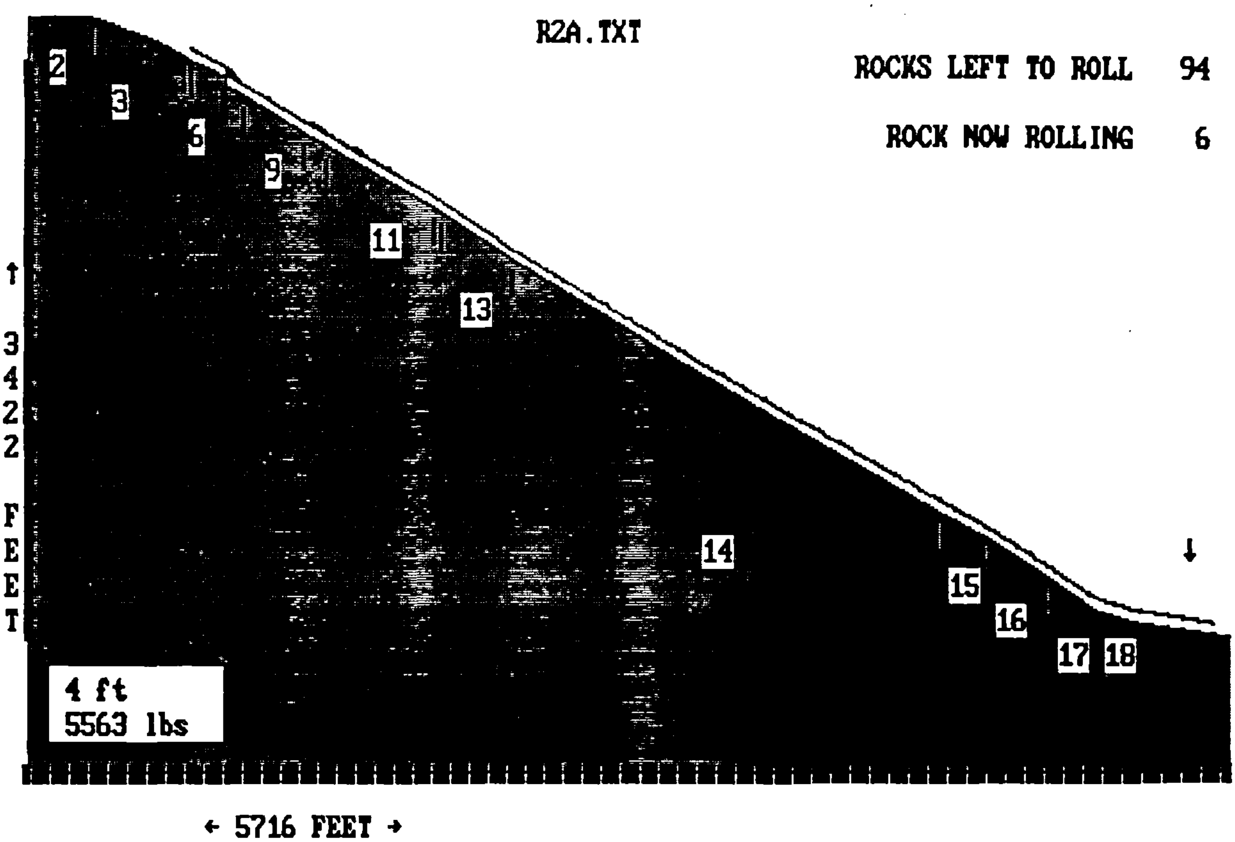
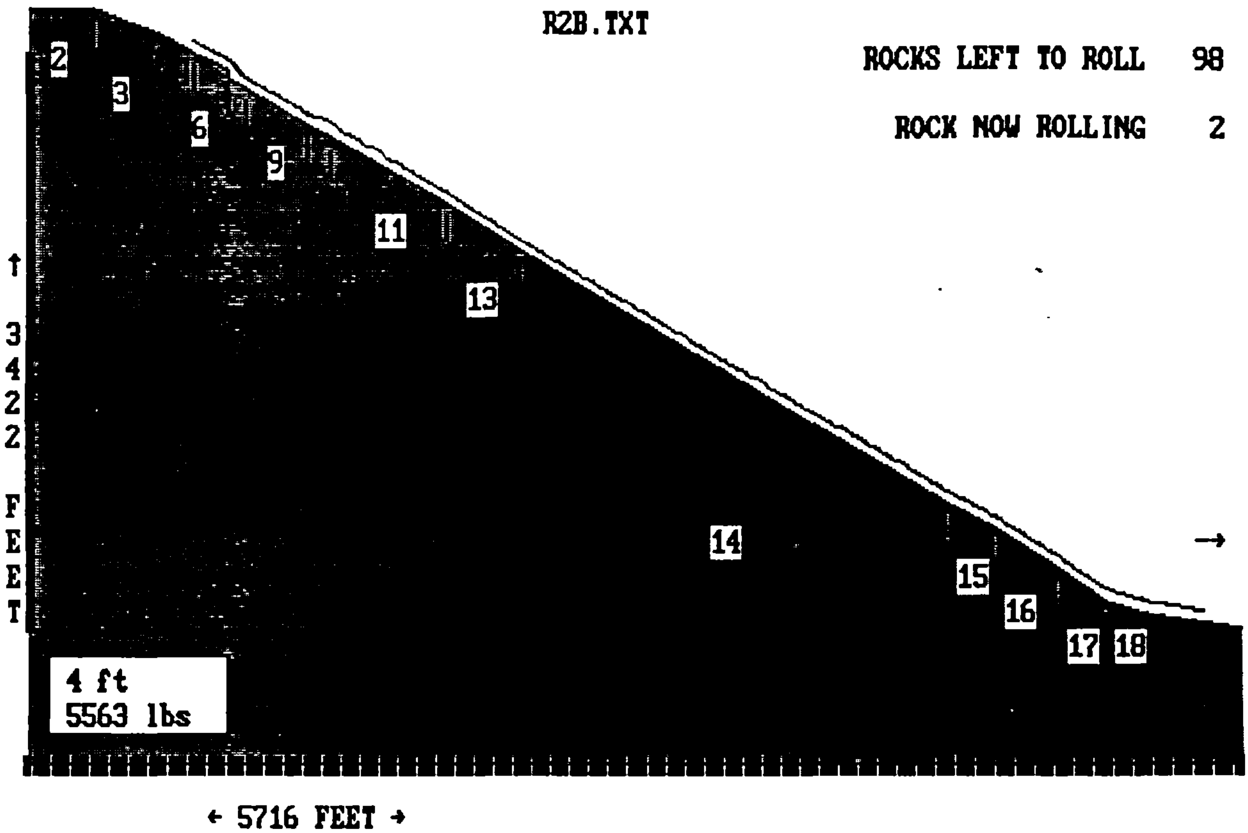


Figure 3. Potential toppling failures.

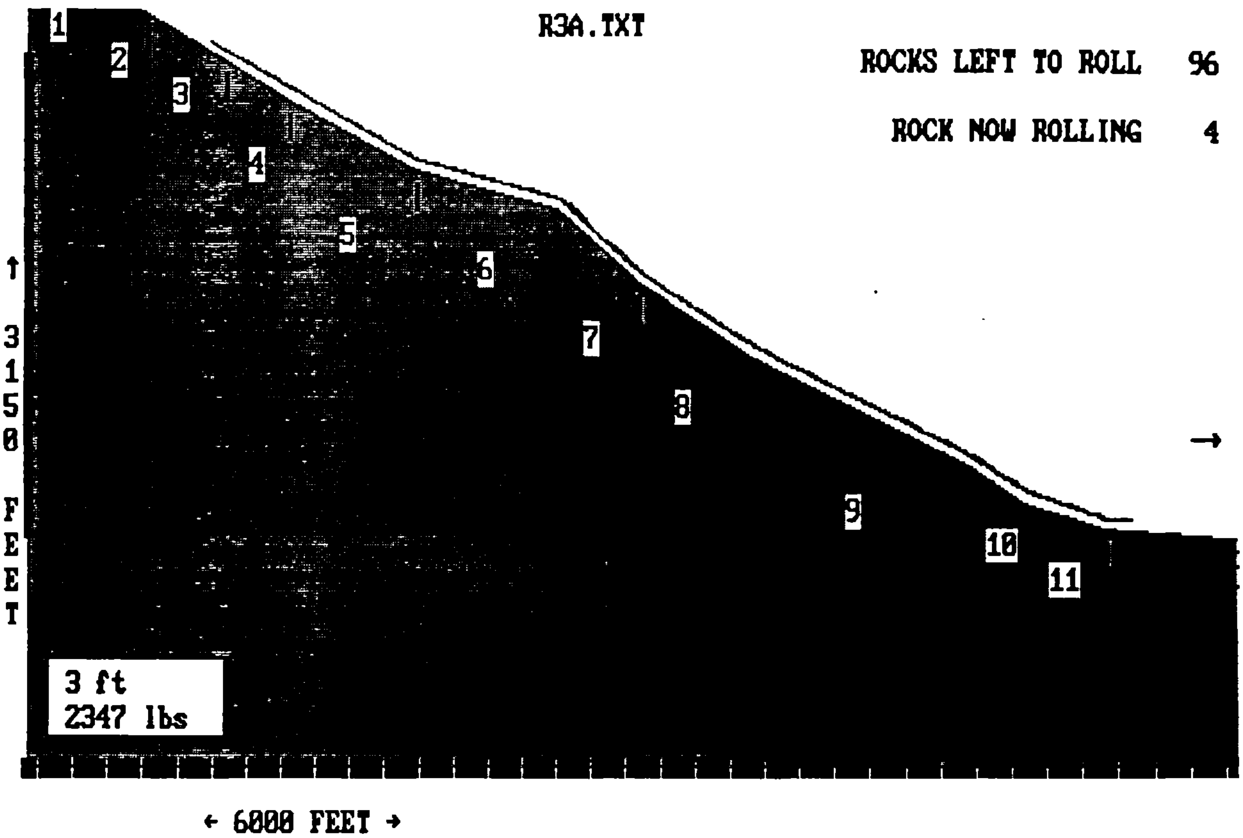
Discontinuities dipping back into a rock mass may cause rock blocks to topple out of the rock mass. The pie-shaped shaded area on the west side of Figure 3 outlines the areas of orientations that could lead to toppling failures. Overturning safety factors should be calculated for discontinuities falling within that area.

For more detailed explanation see ROCKPACK II User's Manual

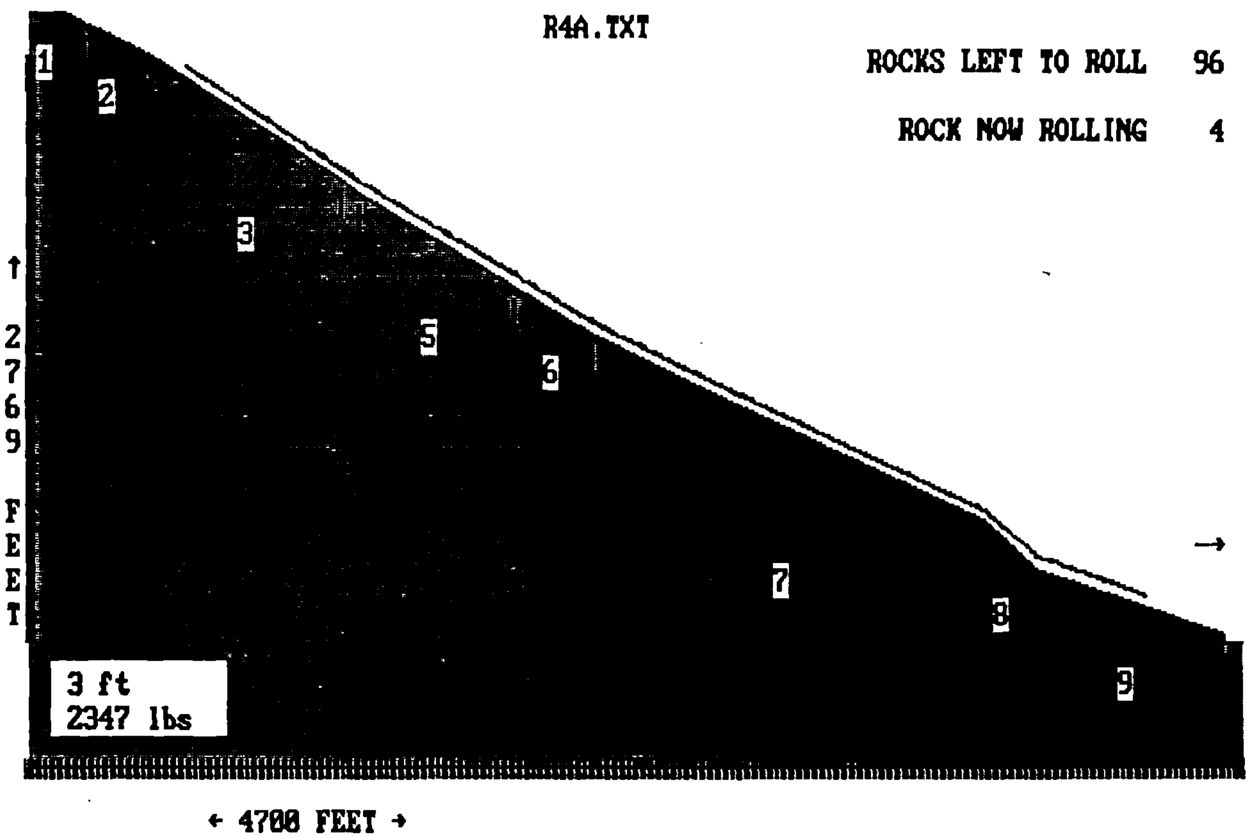

R2A.TXT
ROCKS LEFT TO ROLL 94
ROCK NOW ROLLING 6
2
3
6
9
11
13
14
15
16
17
18
3422 FEET
4 ft
5563 lbs
← 5716 FEET →

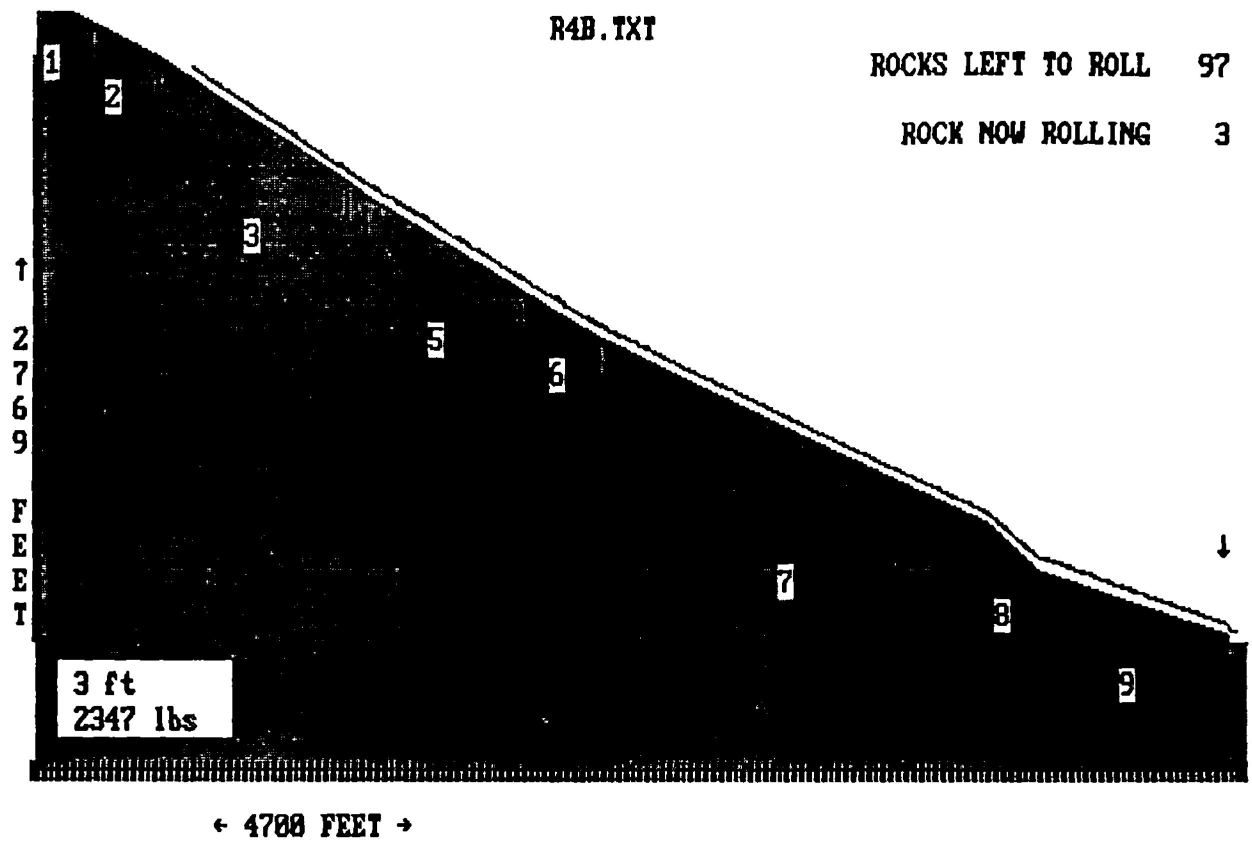


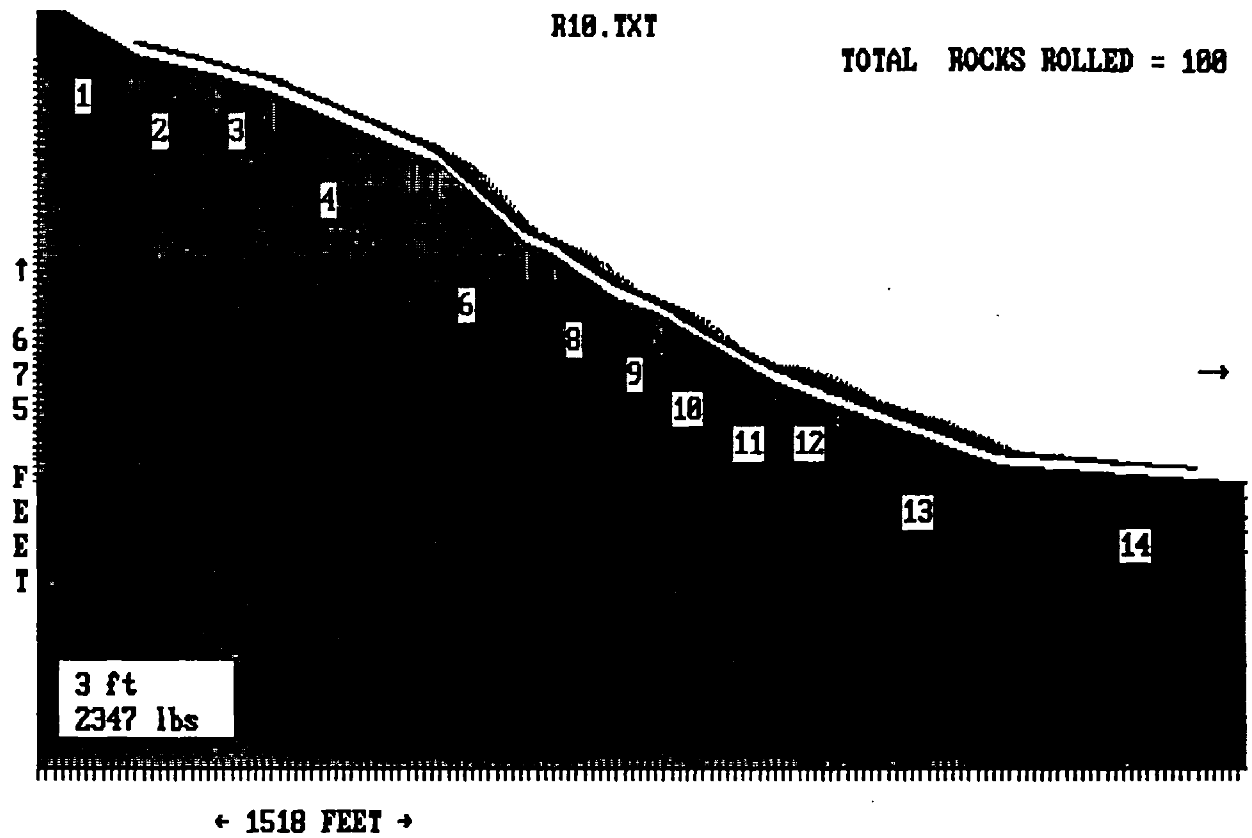
R2B.TXT
ROCKS LEFT TO ROLL 98
ROCK NOW ROLLING 2
3422 FEET
4 ft
5563 lbs
2
3
6
9
11
13
14
15
16
17
18
← 5716 FEET →

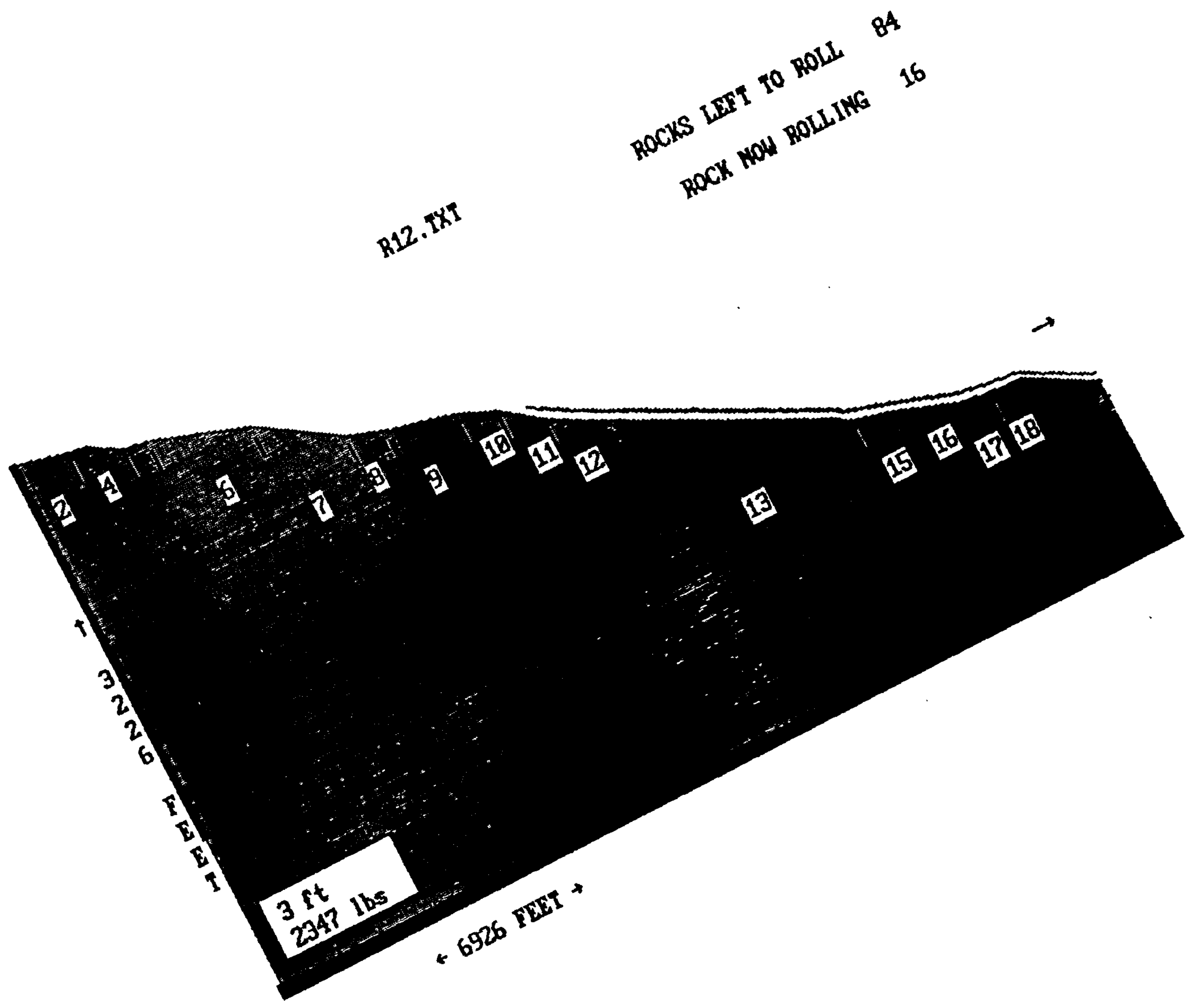


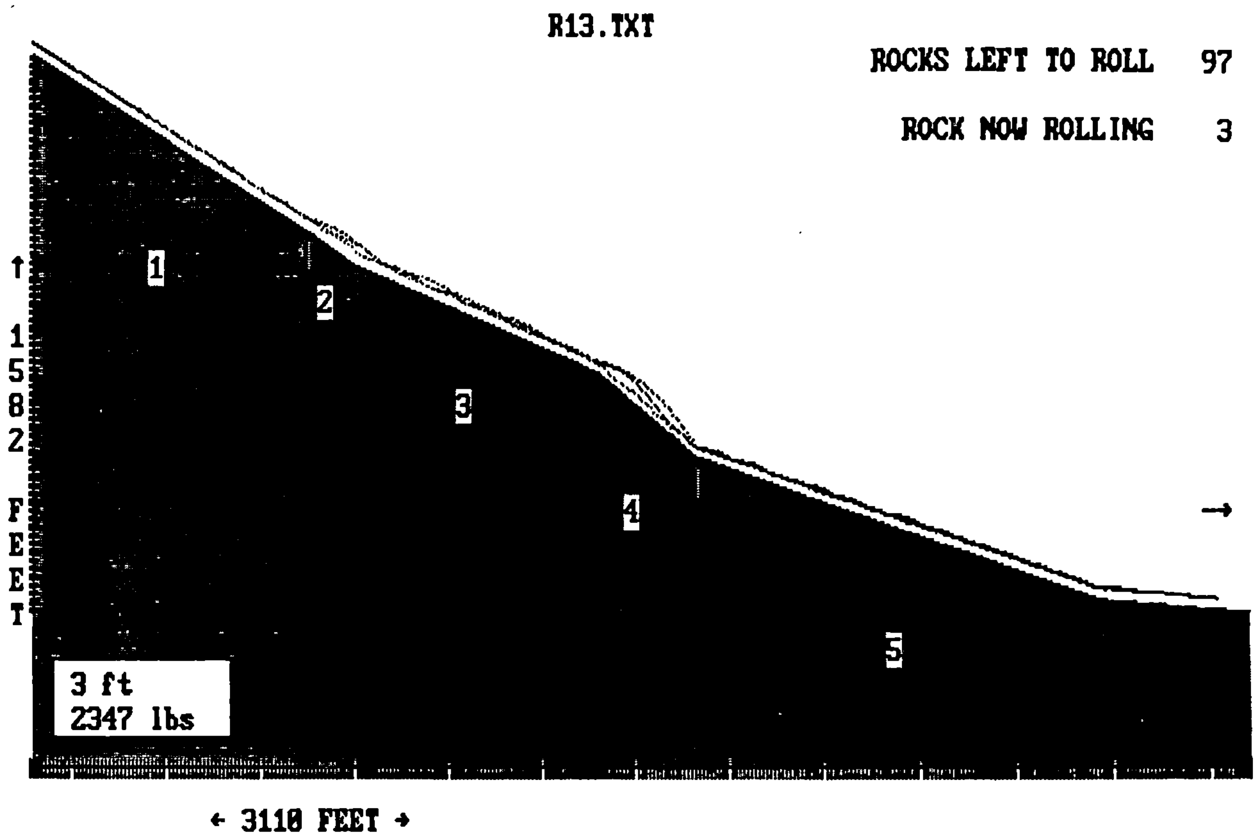
R3A.TXT
ROCKS LEFT TO ROLL 96
ROCK NOW ROLLING 4
1
2
3
4
5
6
7
8
9
10
11
3150 FEET
3 ft
2347 lbs
← 6000 FEET →

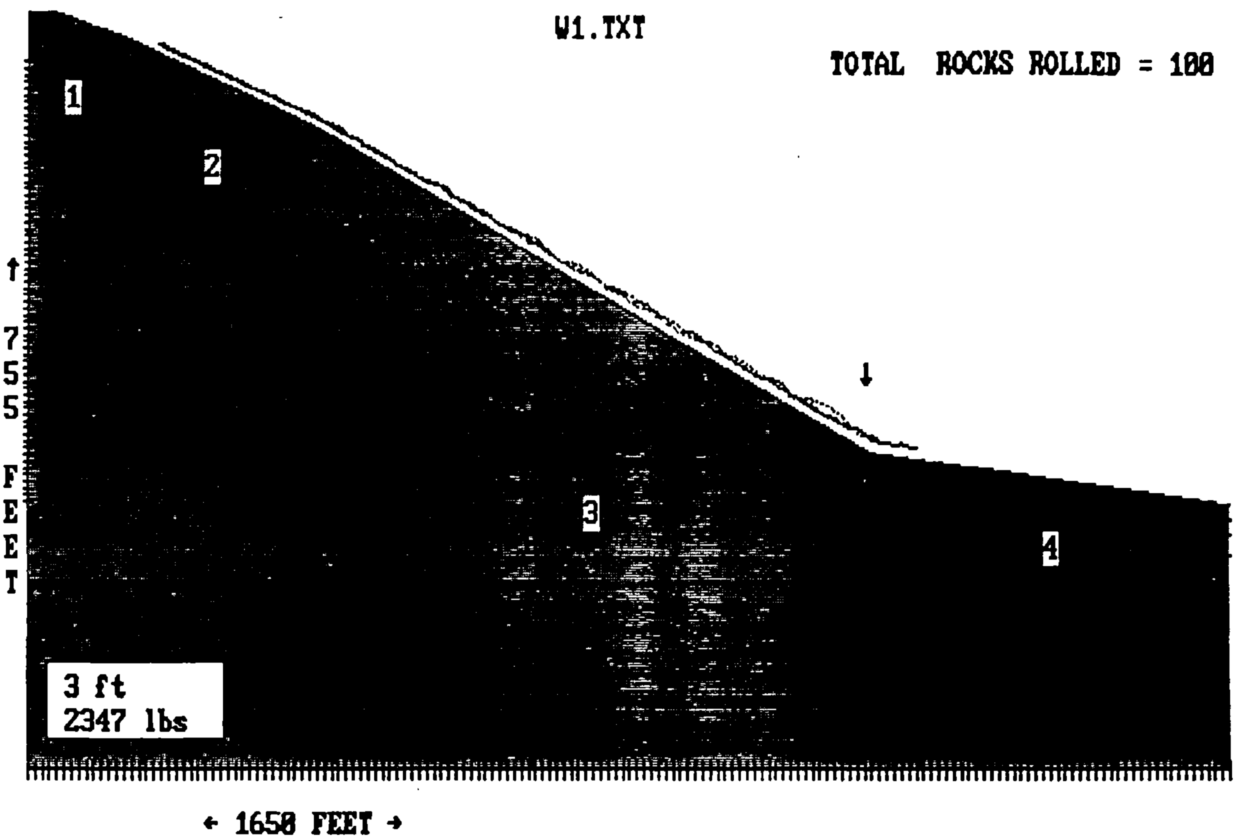

R4A.TXT
ROCKS LEFT TO ROLL 96
ROCK NOW ROLLING 4
2769 FEET
3 ft
2347 lbs
1
2
3
5
6
7
8
9
← 4700 FEET →


R4B.TXT
ROCKS LEFT TO ROLL 97
ROCK NOW ROLLING 3
1
2
3
5
6
7
8
9
2769 FEET
3 ft
2347 lbs
← 4700 FEET →


R10.TXT
TOTAL ROCKS ROLLED = 100
1
2
3
4
6
8
9
10
11
12
13
14
675 FEET
3 ft
2347 lbs
1518 FEET


ROCKS LEFT TO ROLL 84
ROCK NOW ROLLING 16
R12.TXT
2
4
6
7
8
9
10
11
12
13
15
16
17
18
3226 FEET
3 ft
2347 lbs
← 6926 FEET →


R13.TXT
ROCKS LEFT TO ROLL 97
ROCK NOW ROLLING 3
1582 FEET
1
2
3
4
5
3 ft
2347 lbs
← 3110 FEET →


W1.TXT
TOTAL ROCKS ROLLED = 100
1
2
3
4
755 FEET
3 ft
2347 lbs
1650 FEET

APPENDIX D

Earth Berm - Debris Flow Deflection Trench Cost Estimate Analysis

P. Jones
2/13/95

Wenatchee Debris Flow Deflector Trench - Cost Estimate

Logging, Grubbing, Disposal - $342/sta (@ 60'x100'/43,560 sf/ac = 0.14 ac/sta)

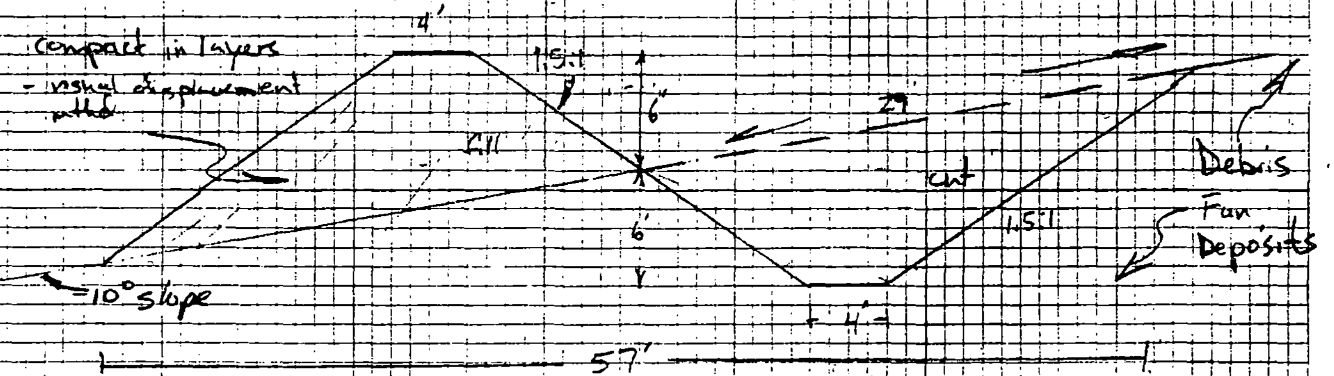
Excavation / Embankment = $646/sta

Seed / mulch = $48/sta

Total $1,036/sta or ≈ $10/linear foot of trench

+ mobilization
D-8 or Lg. Excavator (@50 miles) $611
225, 235
Additional sites $355/move

482 cy/100' trench length - cut
482 cy/100' " " - fill
w/o shrinkage



Logging - Light (8-13" DBH) @ 10 mbf/acre $73.73/mbf $737.30/ac
Grubbing " " $77.42/mbf $774.20/ac

Adj. factor for clearing > 40' = 0.91 x 0.91 $1,375.47/ac

Disposal - Pile & burn, tops, limbs, stumps w/ adj factor = .65 x 1639 = $1065/ac

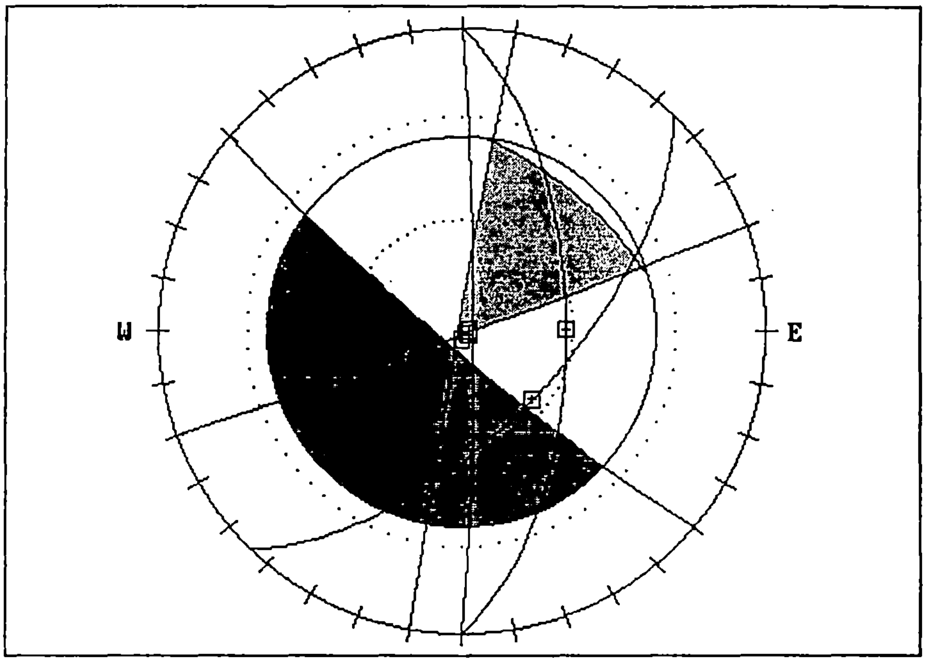
Excavation - Class A 0-15% sideslope @ $1.17/cy x 482 cy = $564/sta

Embankment - Layer Placement $0.17/cy x 482 cy = $82/sta

Seed + mulch w/ Adj factor (1.54) x $173/ac = $266/ac

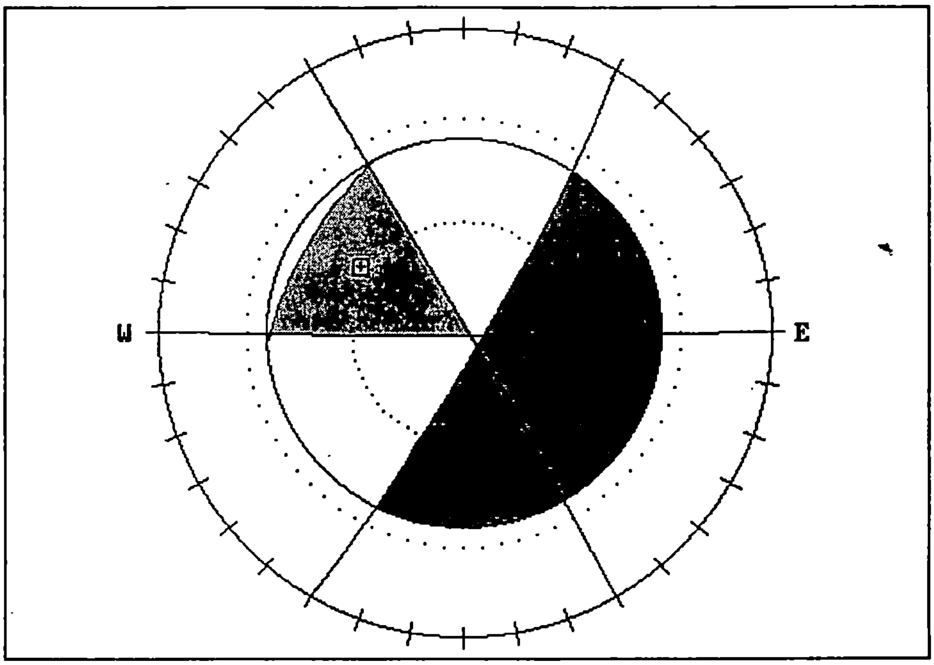
Tumwater Canyon Discontinuity Data

Location	Dip	Dip Dir
T-13 Line 1 Cell 1	33	051
	64	161
	83	304
T-11 Line 1 Cell 4	58	111
	22	251
	85	348
Cell 3	65	120
	33	282
	85	041
T-6 Line 3 Cell 1/4,000 Ft.	40	222
	84	020
	42	230
	20	360
	20	310
Line 5 Cell 1/2,300 Ft.	48	312
	37	50
	71	90
T-5 Cell 2/3,500 Ft.	57	303
T-1 Cell 1/3,900 Ft.	88	116
	64	134
	88	087
	88	180
	62	089
Cell 3/3,400 Ft.	77	180
	68	280
	18	010
	71	271
	82	360
W-1 Line 1 Cell 2	50	324



AREA T-1, LINE 1, CELL 1, 3,900 FT.

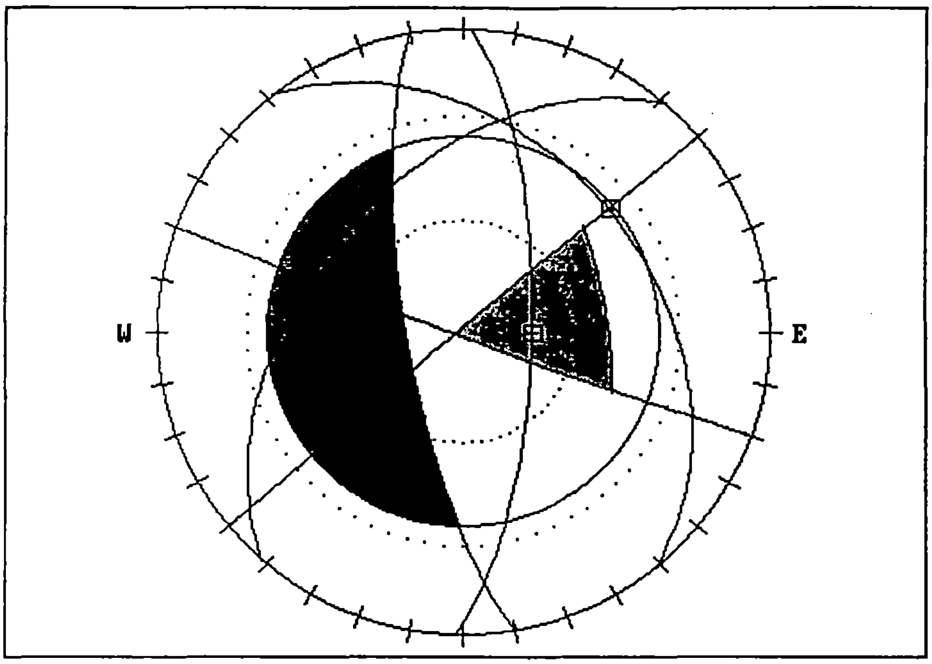
STEREONET PROJECTION OF MAPPED OUTCROP DISCONTINUITIES WHICH DISPLAYS POTENTIAL FOR TOPPLING FAILURE (Shadded wedge-shaped area) AND WEDGE FAILURE (Shadded pie-shapped area)



MARKLAND TEST PLOT: c:\rkpk2-04\data\t512.DAT
Friction Angle = 36 degrees
Slope dip direction = 120 degrees, Dip = 85 degrees
Number of Stations = 1

AREA T-5, LINE 1, CELL 2, 3,500 ft.

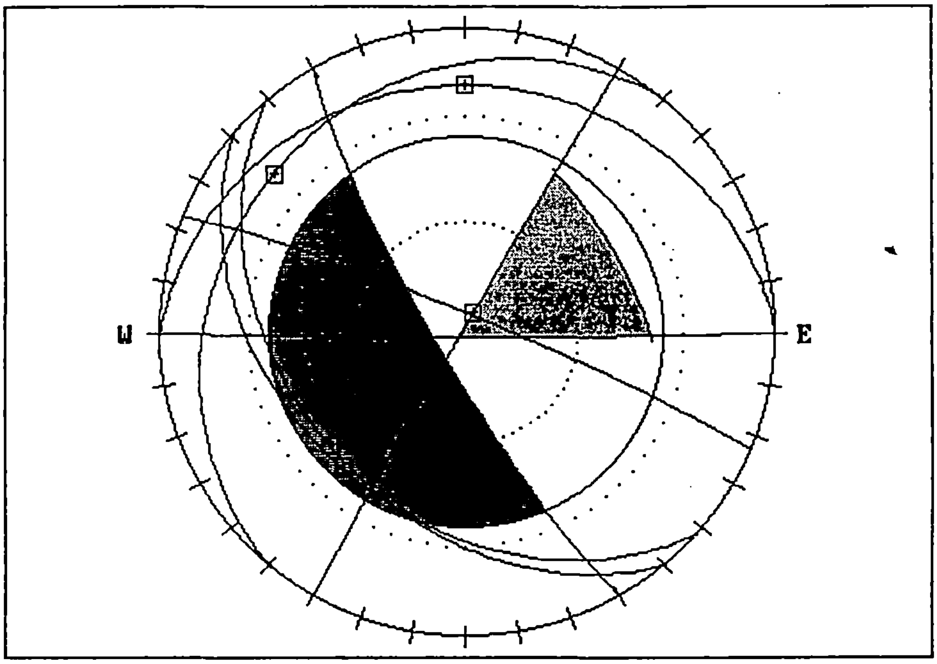
STEREONET PROJECTION OF MAPPED OUTCROP DISCONTINUITIES WHICH DISPLAYS POTENTIAL FOR TOPPLING FAILURE (Shadded wedge-shaped area)



MARKLAND TEST PLOT: c:\rkpk2-04\data\t651.DAT
Friction Angle = 36 degrees
Slope dip direction = 260 degrees, Dip = 75 degrees
Number of Stations = 3

AREA T-6, LINE 5, CELL 1, 2,300 ft.

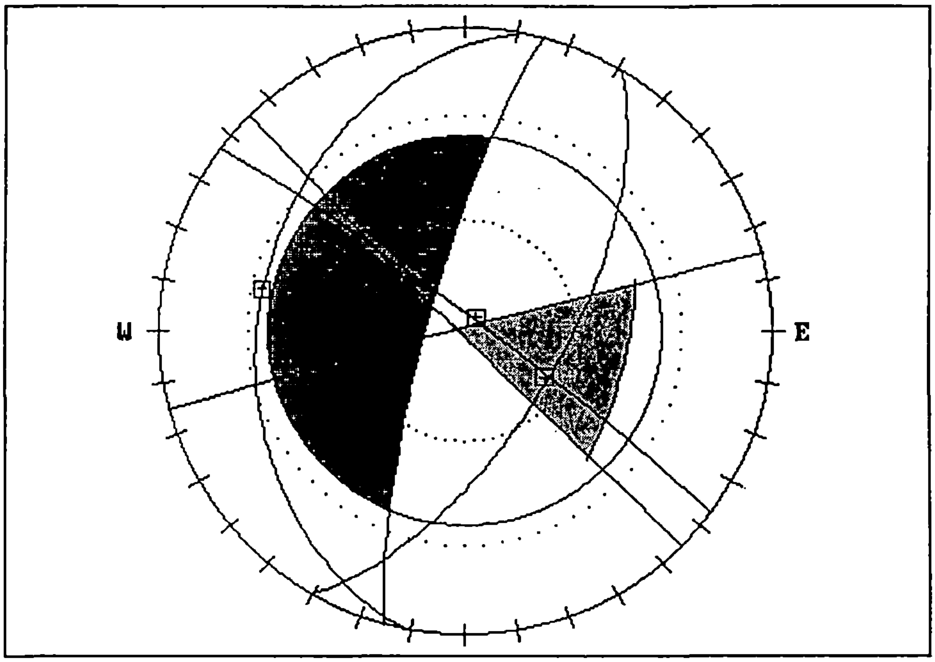
STEREONET PROJECTION OF MAPPED OUTCROP DISCONTINUITIES WHICH DISPLAYS POTENTIAL FOR TOPPLING FAILURE (Shadded wedge-shaped area)



MARKLAND TEST PLOT: c:\rkpk2-04\data\t631.DAT
Friction Angle = 36 degrees
Slope dip direction = 240 degrees, Dip = 82 degrees
Number of Stations = 5

AREA T-6, LINE 3, CELL 1/4,000 FT.

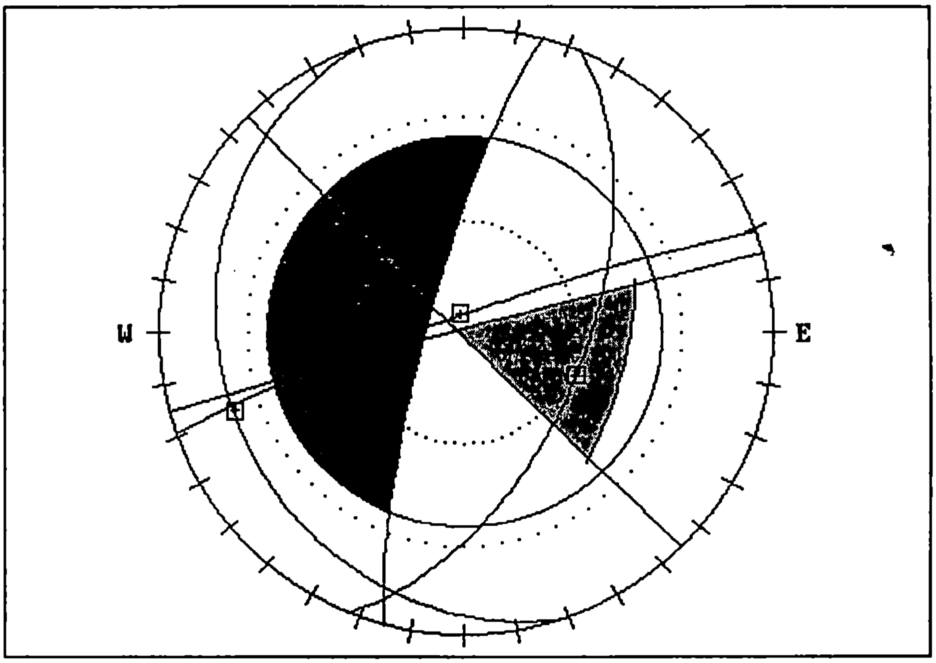
STEREONET PROJECTION OF MAPPED OUTCROP DISCONTINUITIES WHICH DISPLAYS POTENTIAL FOR TOPPLING FAILURE (Shadded wedge-shaped area), PLANE AND WEDGE FAILURE (Shadded pie-shapped area)



MARKLAND TEST PLOT: c:\rkpk2-04\data\t1113.DAT
Friction Angle = 36 degrees
Slope dip direction = 285 degrees, Dip = 80 degrees
Number of Stations = 3

AREA T-11, LINE 1, CELL 3

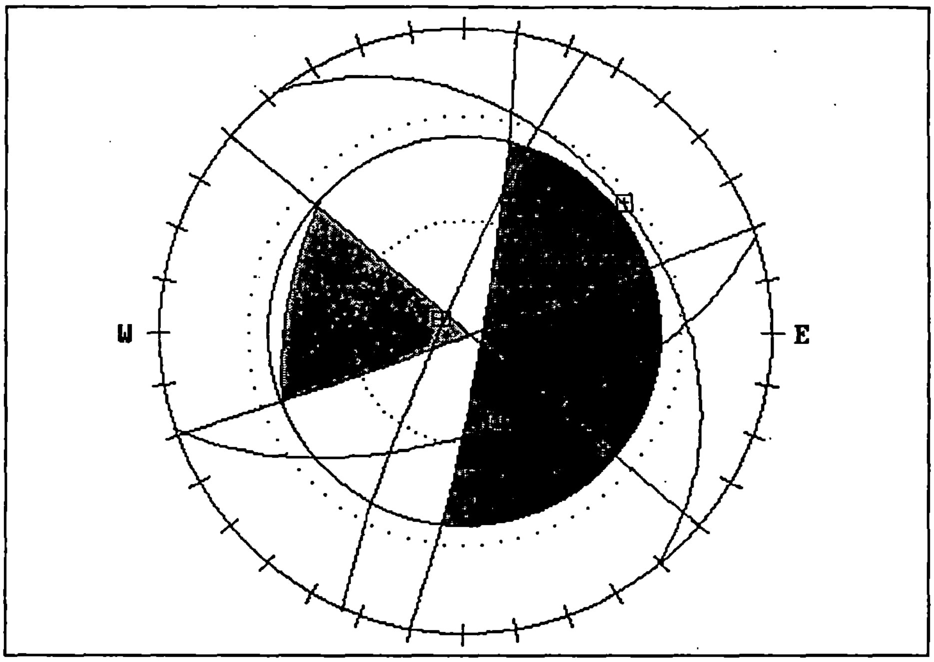
STEREONET PROJECTION OF MAPPED OUTCROP DISCONTINUITIES WHICH DISPLAYS POTENTIAL FOR TOPPLING FAILURE (Shadded wedge-shaped area)



MARKLAND TEST PLOT: c:\rkpk2-04\data\t1114.DAT
Friction Angle = 36 degrees
Slope dip direction = 285 degrees, Dip = 80 degrees
Number of Stations = 3

AREA T-11, LINE 1, CELL 4

STEREONET PROJECTION OF MAPPED OUTCROP DISCONTINUITIES WHICH DISPLAYS POTENTIAL FOR TOPPLING FAILURE (Shadded wedge-shaped area)



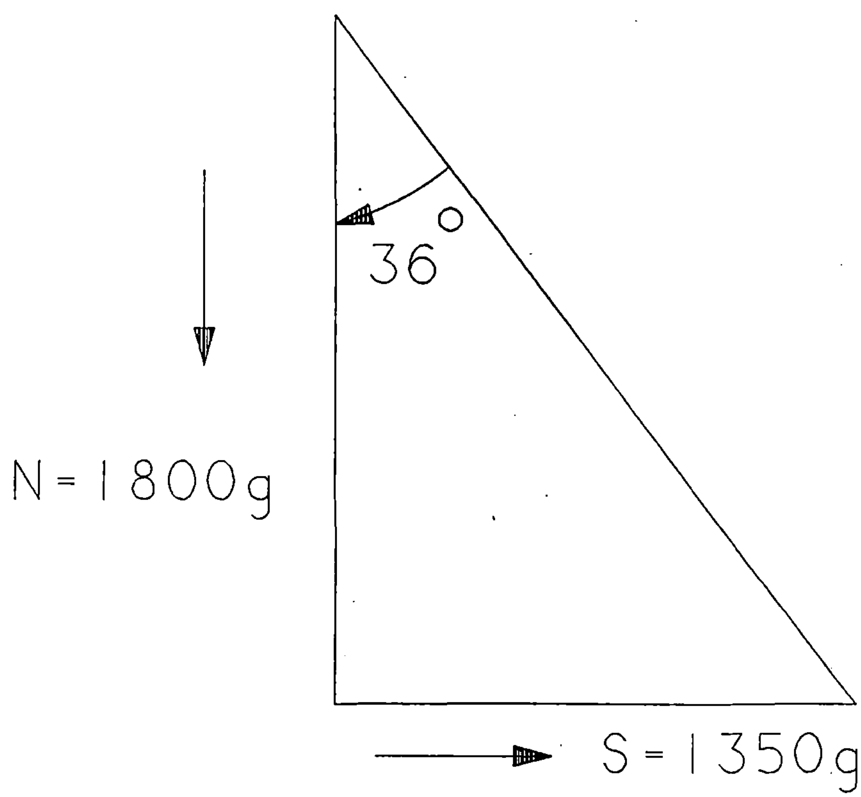
MARKLAND TEST PLOT: c:\rkpk2-04\data\t1311.DAT
Friction Angle = 36 degrees
Slope dip direction = 100 degrees, Dip = 85 degrees
Number of Stations = 3

AREA T-13, LINE 1, CELL 1

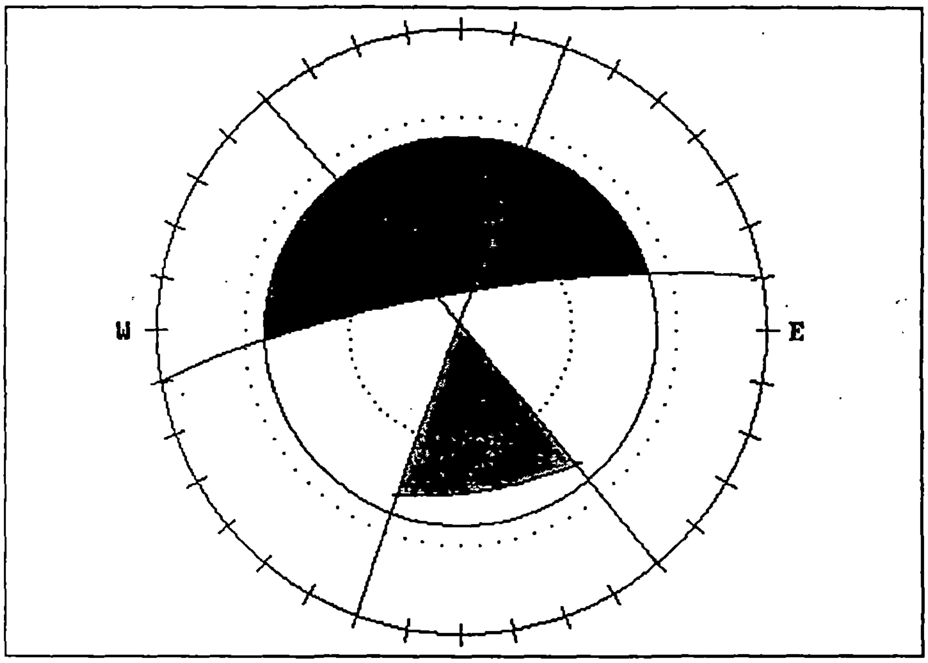
STEREONET PROJECTION OF MAPPED OUTCROP DISCONTINUITIES WHICH DISPLAYS POTENTIAL FOR TOPPLING FAILURE (Shadded wedge-shaped area)

FORCE DIAGRAM

MT. STEWART BATHOLITH
PULL TEST



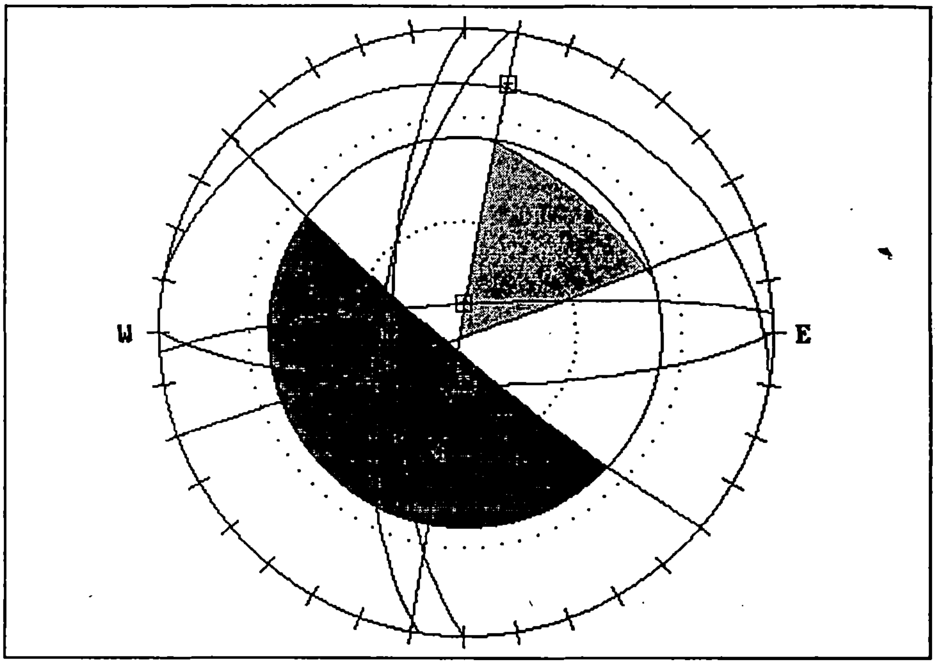
SCALE 1 inch = 500 grams



MARKLAND TEST PLOT: c:\rkpk2-04\data\w112.DAT
Friction Angle = 36 degrees
Slope dip direction = 350 degrees, Dip = 80 degrees
Number of Stations = 1

AREA W-1, LINE 1, CELL 2

STEREONET PROJECTION OF MAPPED OUTCROP DISCONTINUITIES WHICH DISPLAYS POTENTIAL FOR PLANE FAILURE (Shadded pie-shaped area)



MARKLAND TEST PLOT: c:\rkpk2-04\data\t113.DAT
Friction Angle = 36 degrees
Slope dip direction = 220 degrees, Dip = 85 degrees
Number of Stations = 5

AREA T-1, LINE 1, CELL 3, 3,400 FT.

STEREONET PROJECTION OF MAPPED OUTCROP DISCONTINUITIES WHICH DISPLAYS POTENTIAL FOR TOPPLING FAILURE (Shadded wedge-shaped area) AND WEDGE FAILURE (Shadded pie-shapped area)

HATCHERY FIRE COMPLEX, LEVENWORTH, WA
SLOPE STABILITY ASSESSMENT FOR ROCKFALL
TUMWATER AND ICICLE CANYONS

Colorado Rockfall Simulation Program File Notes

TUMWATER CANYON SITES

T1.TXT

This section simulates two boulder dams that have developed on the lower slope that are between 8 and 9 feet high, which prevent rocks from rolling past cell 12.
Lower section analysis (Cells 7-12)
Initiation in Cell #7
Changed S values from notes
2-4 ft. rocks...none made it to road.

T2

Not Modeled....natural catchment area 200 ft. wide below upslope source...Heavy timbered section below burn area..2,000 ft. to road.

T3NUM3A.TXT

Source area at headwall..large outcrop area...
High intensity burn site..feeds debris avalanche chute (T3NUM3B,TXT)

T3NUM3B.TXT

Very rough boulder accumulation chute..see photos..
1.5 ft. rocks...none make it to analysis point (1,400 ft. upslope of road)
2.5 ft. rocks...42 make it to analysis point..100 rolled
4.0 ft. rocks..98 make it to analysis point..

T3NUM1.TXT

Analysis Section
From top of slope to road
2 ft. rocks...none reach the road
4 ft. rocks...1 rock reaches road out of 100 rolled
8 ft. rocks...15 reach road out of 100 rolled (not more than 20 observed)

T4.TXT

Areas T4 and T5 converge to a common pathway below their burned areas.

Slope extended from cell 7 to bottom from topo map.
Rt = .5 in cells 7/8 due to heavy timber
2 ft. rocks...6 make it to road out of 100 rolled
3 ft. rocks...10 make it to road out of 10 rolled

T5A.TXT

Slope extended from cell 5 to bottom from topo map.
S value incresed in cell #2 doe to accumulation zone.
Rt decresed to .5 due to heavy timber.
1 ft. rocks...none make it to road
3 ft. rocks...3 make it to road out of 100 rolled

T6NUM1A.TXT

No rocks rolled...too flat

T6A.TXT

T6 A/B are routes that were measured on the north and south sides of T6. They converge to a common pathway below the burned area.

3 ft. rocks...none make it to road

T6B.TXT

Adjusted Rt down to 0.7 to account for timber
Approximated roughness based on photos and notes
2 ft. rocks...none make it to road
3 ft rocks....1 out of 100 make it to road
4 ft. rocks...56 make it to road out of 100.
12 ft. rock...one observed on monolithic block with through-going discontinuity dipping at 34 degrees...

T7/T8

Soil Slope Stability Areas...not modeled for rockfall.

T9

Not modeled..Natural catchment area at 2400-2600 ft. elevation with 500 ft. runout zone.

T10.TXT

2 ft. rocks..none make it to road
3 ft. rocks...44 out of 100 rolled make it to road
S values increased
Cells 4,5,6 estimated in office

T11.TXT

T11 represents both chanels of T11A/B

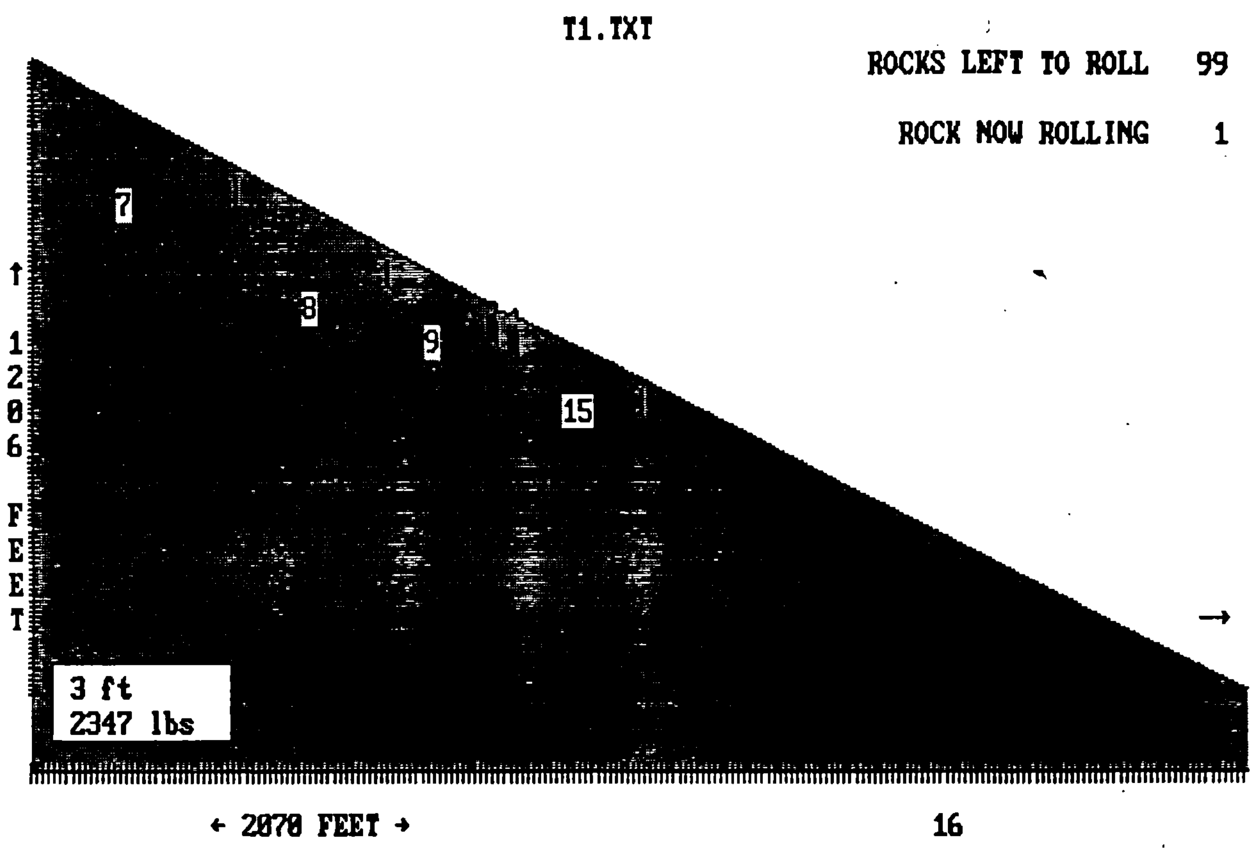
Initiation in cel #1.
1 ft. rocks...none make it to road
2 ft. rocks...none make it to road
3 ft rocks...30 make it to road out of 100 rolled.
This area had a debris avalanch failure that blocked the north-bound traffic on Oct 20th.

T12.txt

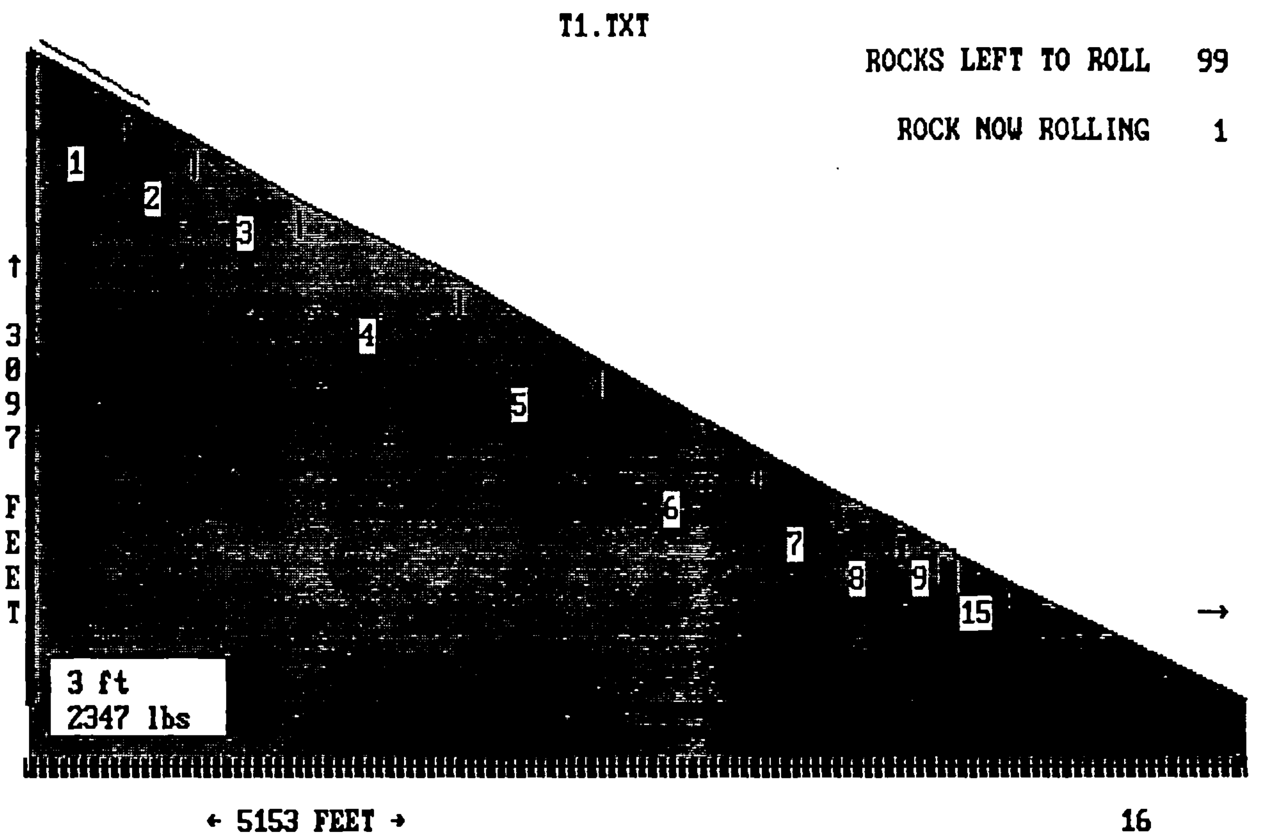
1 ft. rocks..none make it ot road
2 ft. rocks...1 makes it to road out of 100 rolled

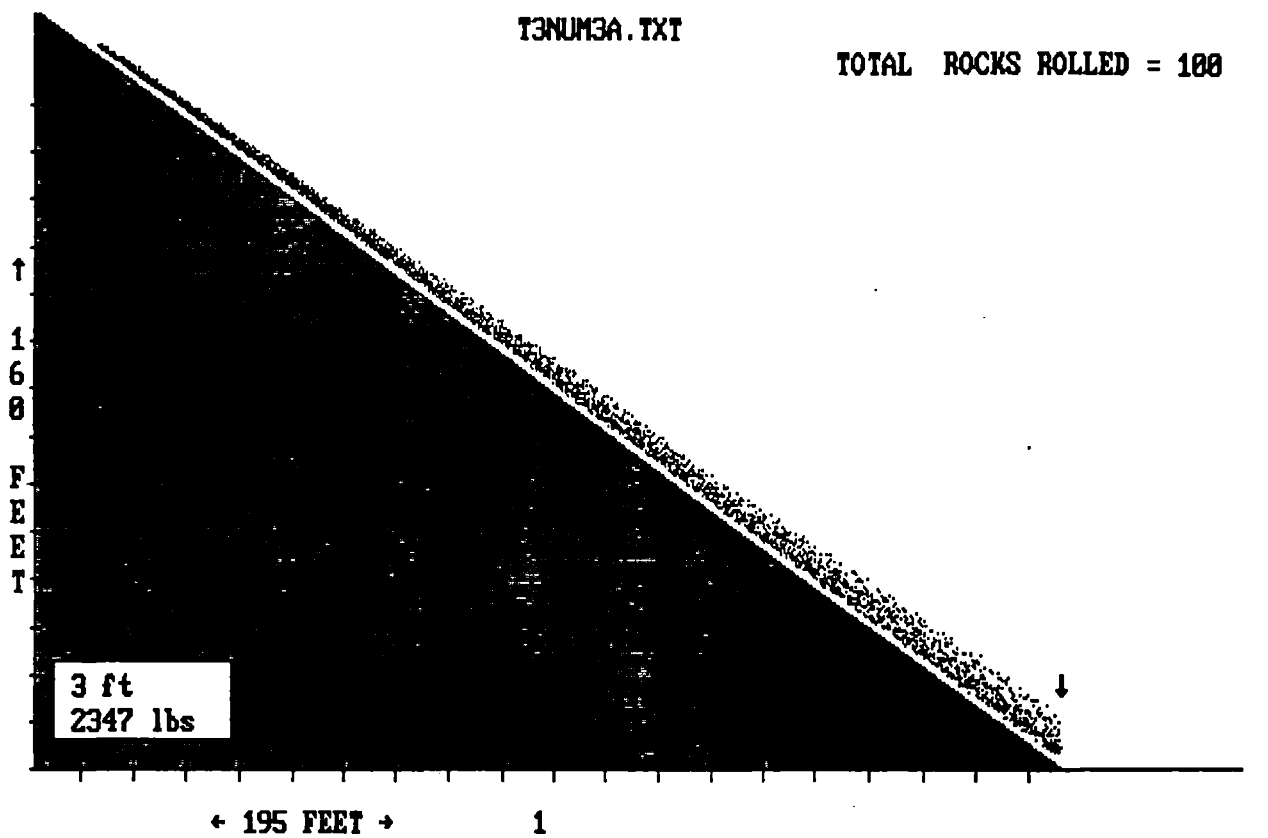
T13.TXT

Initiation in cell #1
Increased S values
1.5 ft. rocks..none made it past the fan toe
2 ft. rocks...24 made it to the toe of the fan

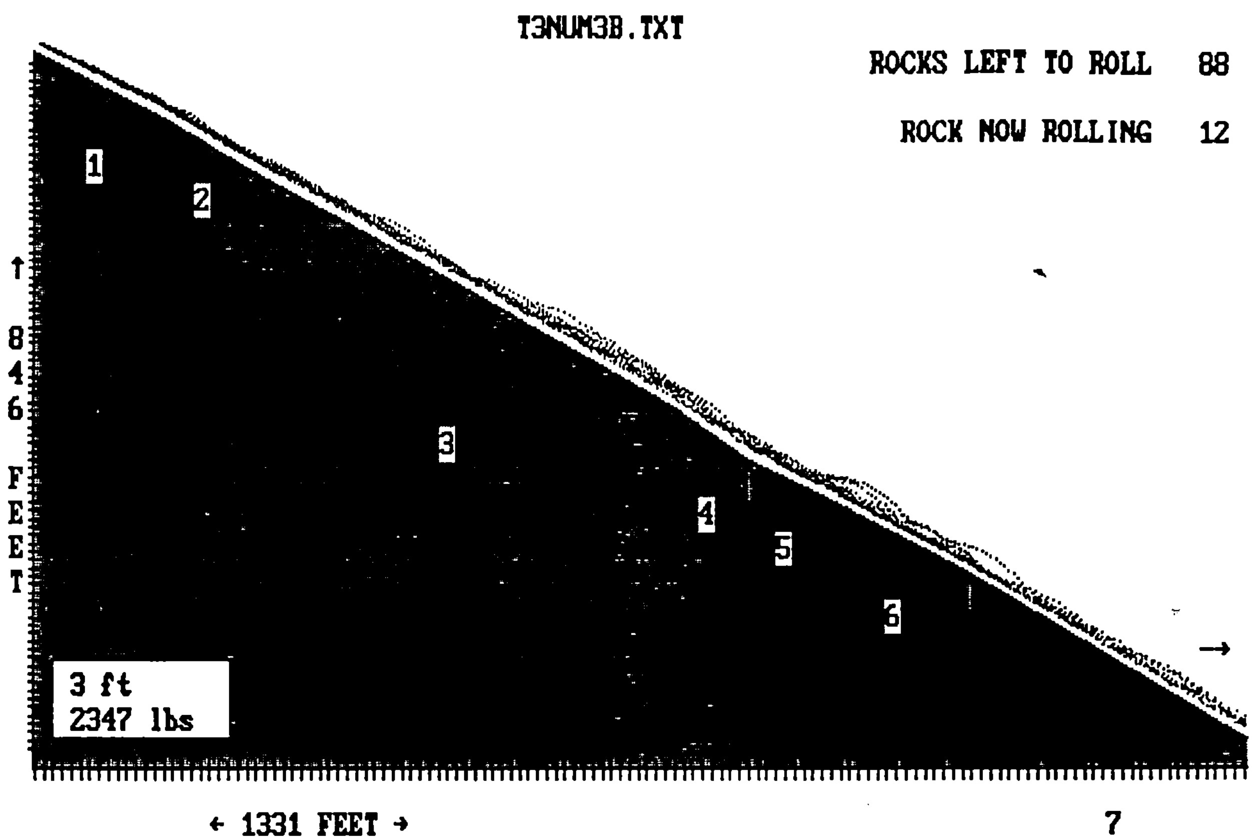


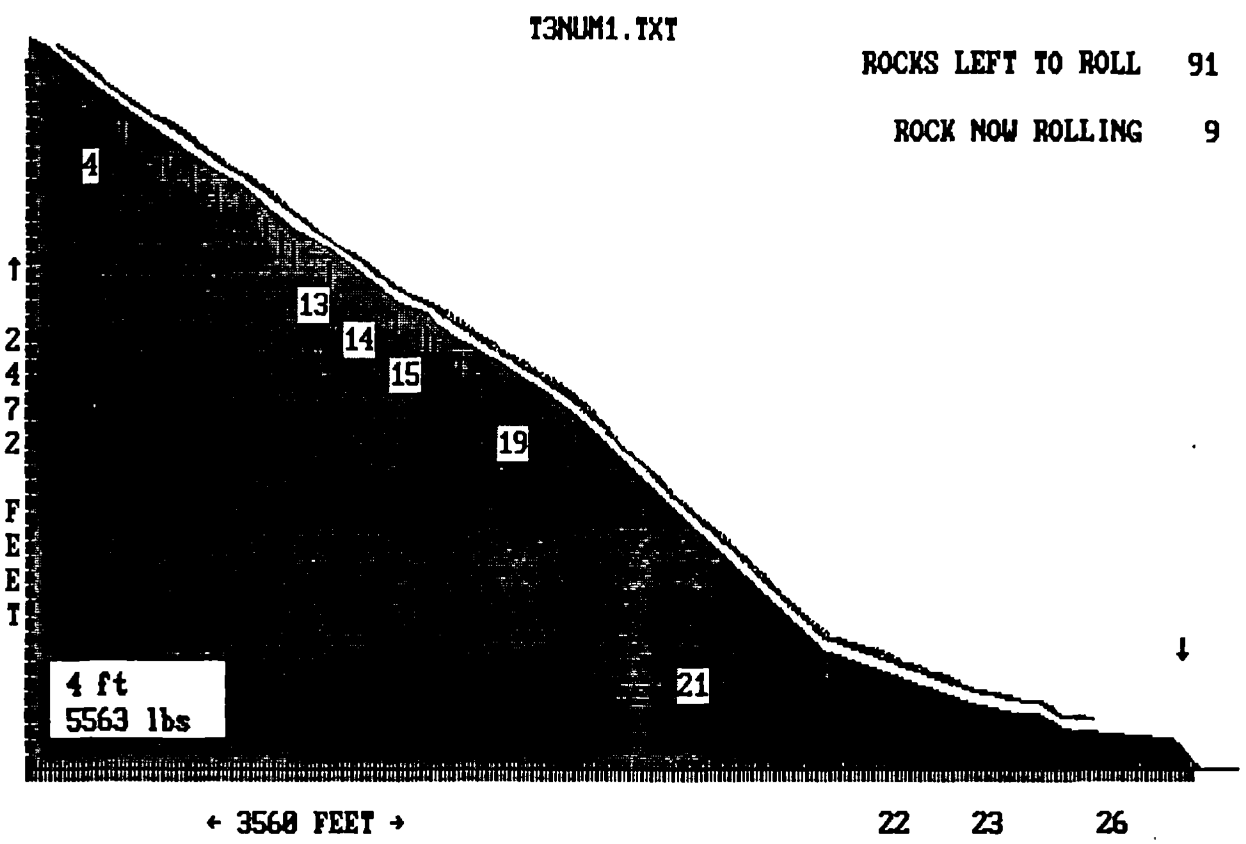
T1.TXT
ROCKS LEFT TO ROLL 99
ROCK NOW ROLLING 1
7
8
9
15
1206 FEET
3 ft
2347 lbs
← 2070 FEET →
16


T1.TXT
ROCKS LEFT TO ROLL 99
ROCK NOW ROLLING 1
1
2
3
4
5
6
7
8
9
15
3097 FEET
3 ft
2347 lbs
← 5153 FEET →
16

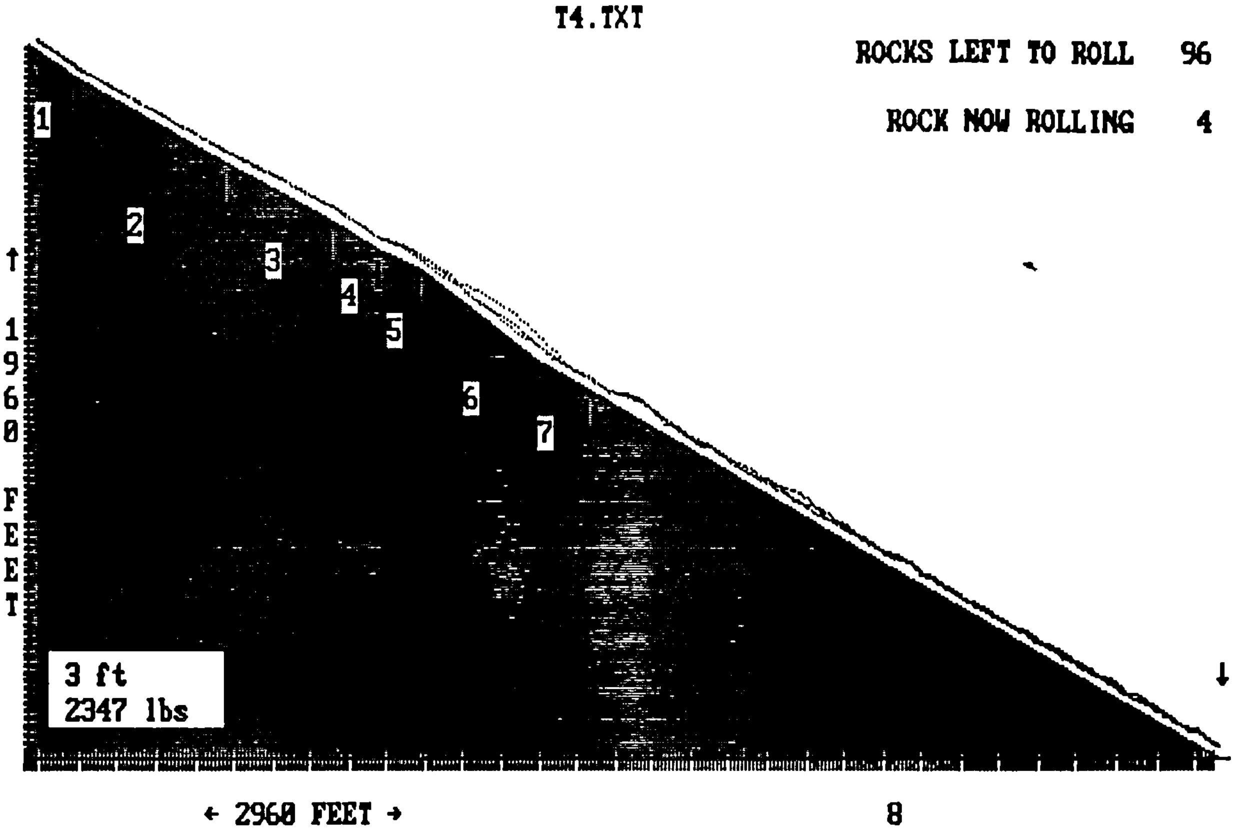


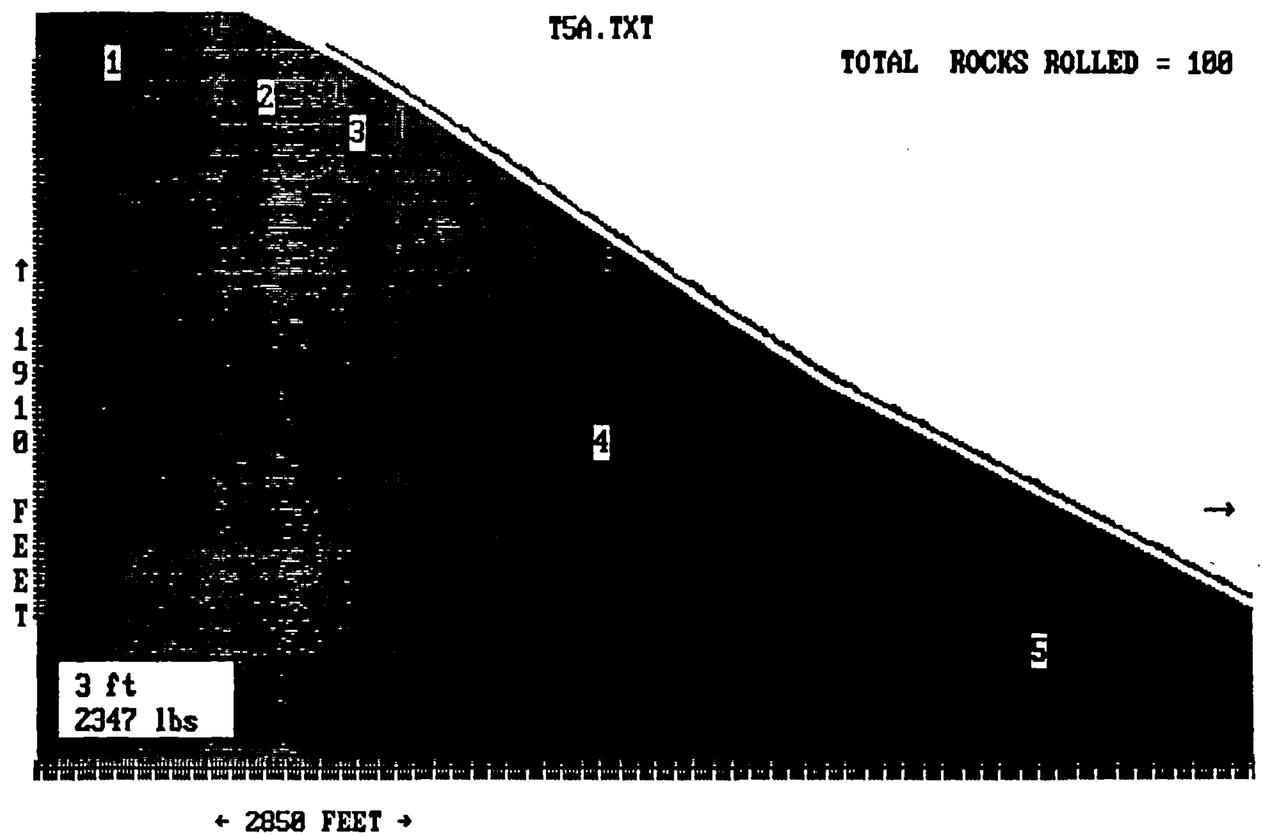
T3NUM3A.TXT
TOTAL ROCKS ROLLED = 100
160 FEET
3 ft
2347 lbs
← 195 FEET →
1

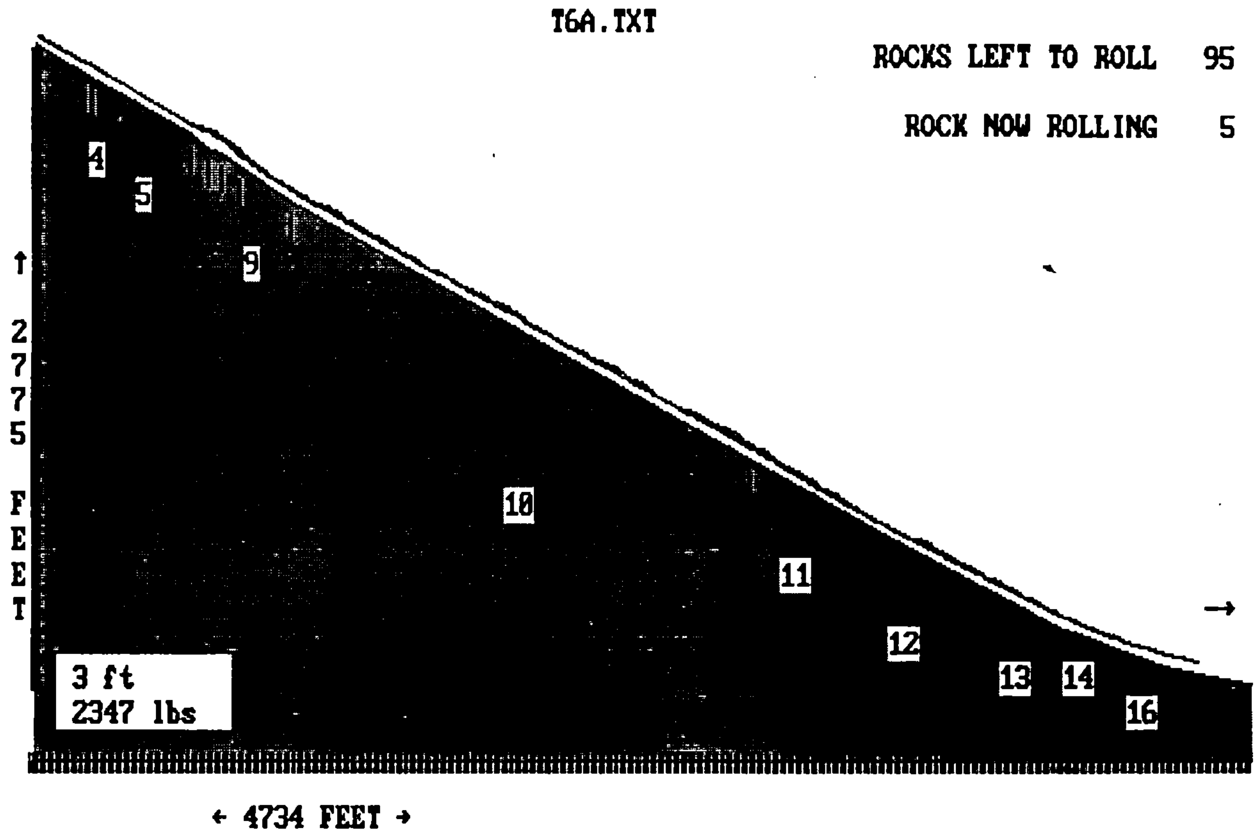

T3NUM3B.TXT
ROCKS LEFT TO ROLL 88
ROCK NOW ROLLING 12
1
2
3
4
5
6
↑ 846 FEET
3 ft
2347 lbs
← 1331 FEET →

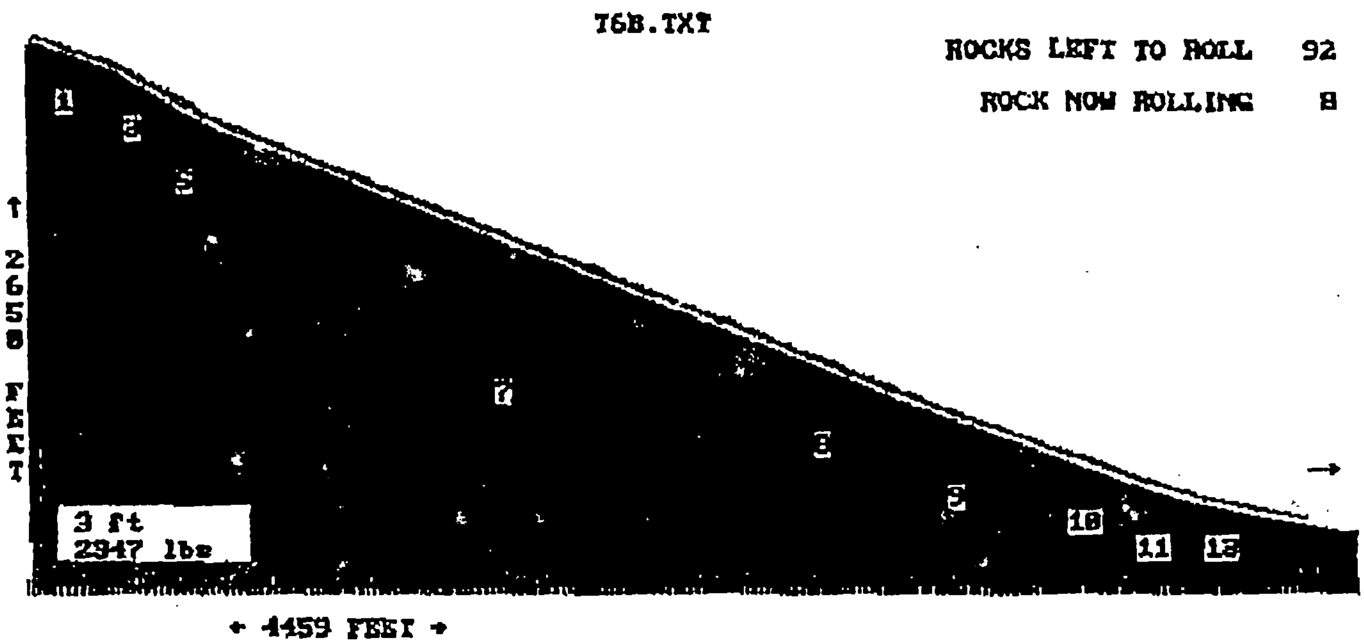


T3NUM1.TXT
ROCKS LEFT TO ROLL 91
ROCK NOW ROLLING 9
4
13
14
15
19
21
2472 FEET
4 ft
5563 lbs
← 3560 FEET →
22
23
26

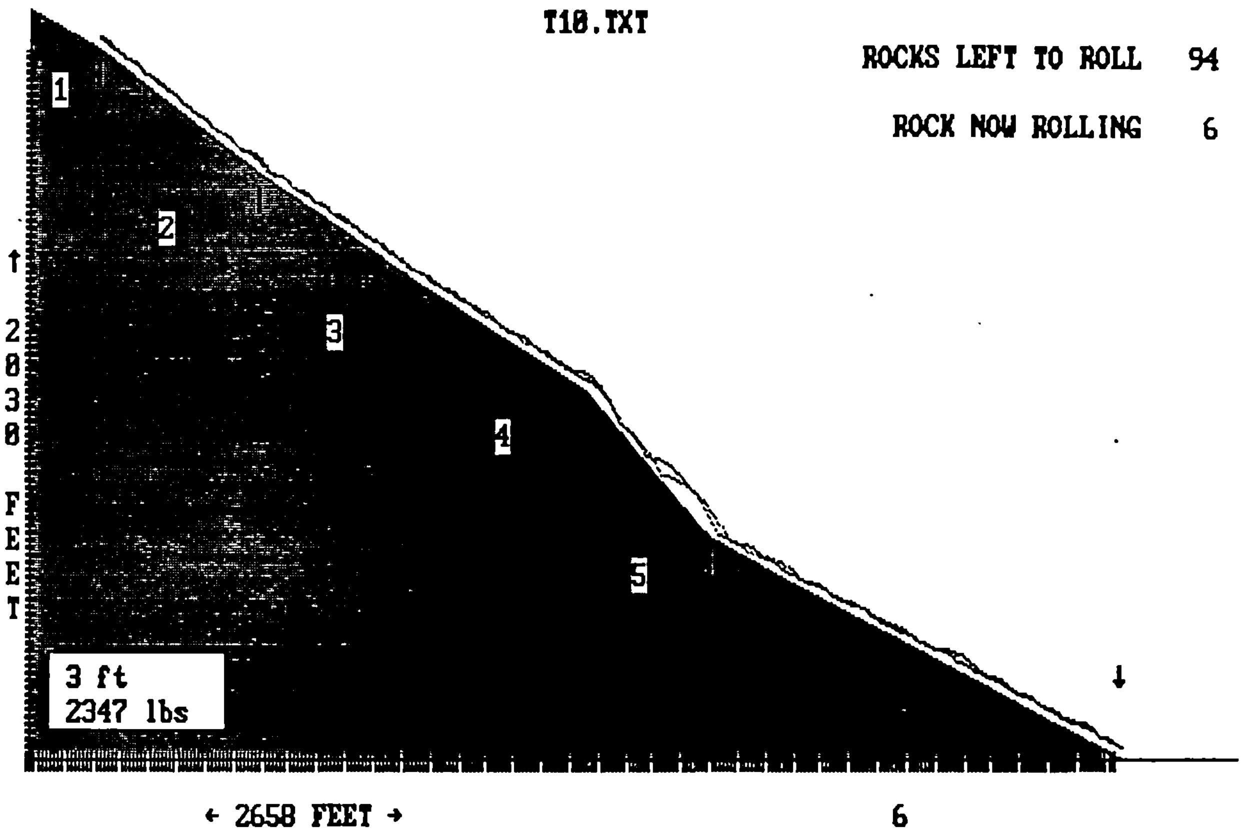

T4.TXT
ROCKS LEFT TO ROLL 96
ROCK NOW ROLLING 4
↑ 1960 FEET ↓
1
2
3
4
5
6
7
3 ft
2347 lbs
← 2960 FEET →

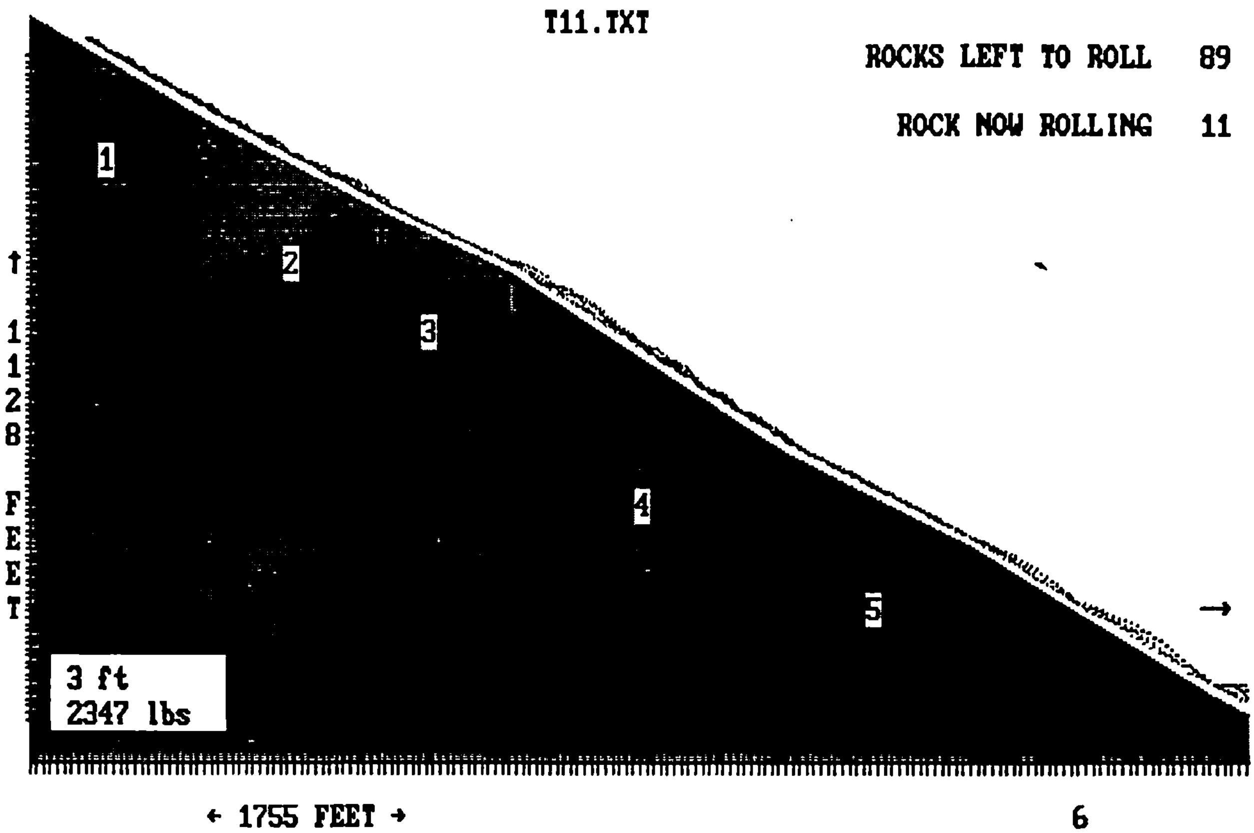

T5A.TXT
TOTAL ROCKS ROLLED = 100
1
2
3
4
5
1910 FEET
3 ft
2347 lbs
← 2850 FEET →

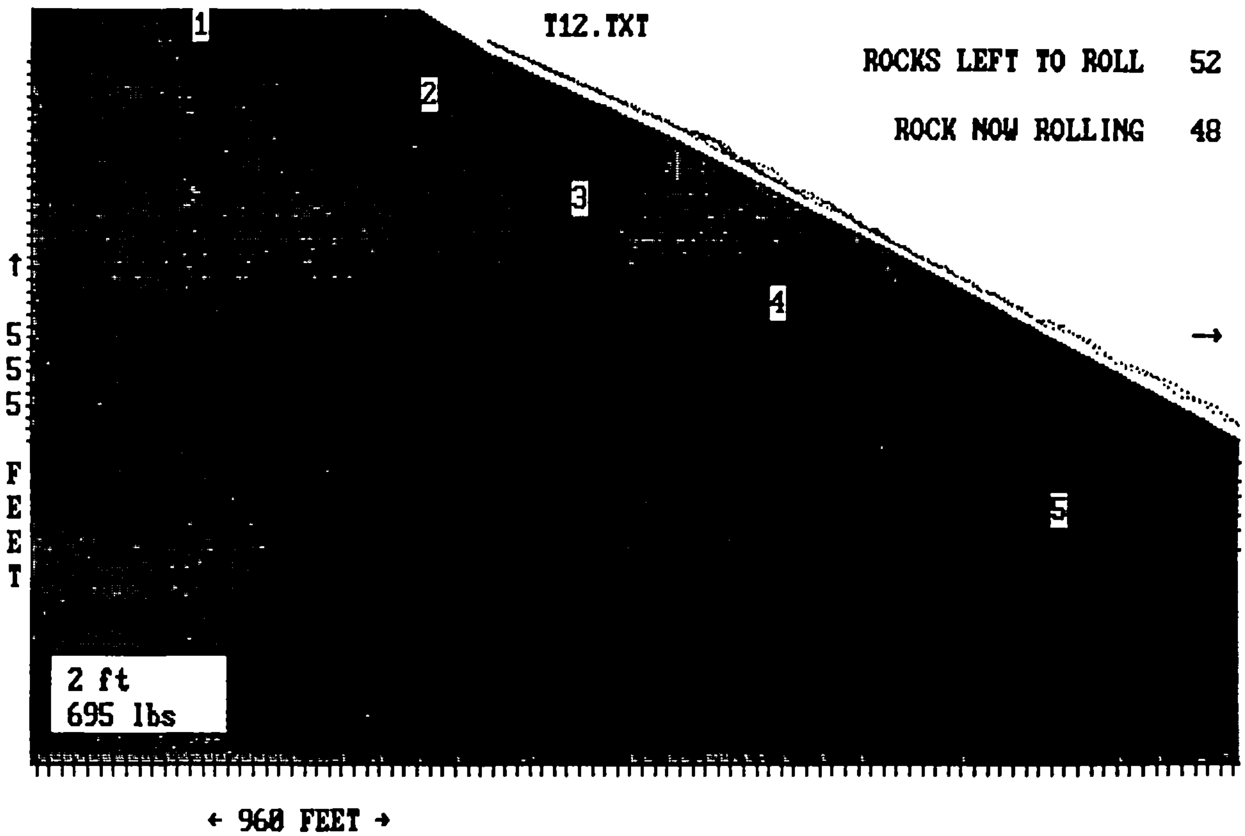

T6A.TXT
ROCKS LEFT TO ROLL 95
ROCK NOW ROLLING 5
4
5
9
10
11
12
13
14
16
2775 FEET
3 ft
2347 lbs
4734 FEET



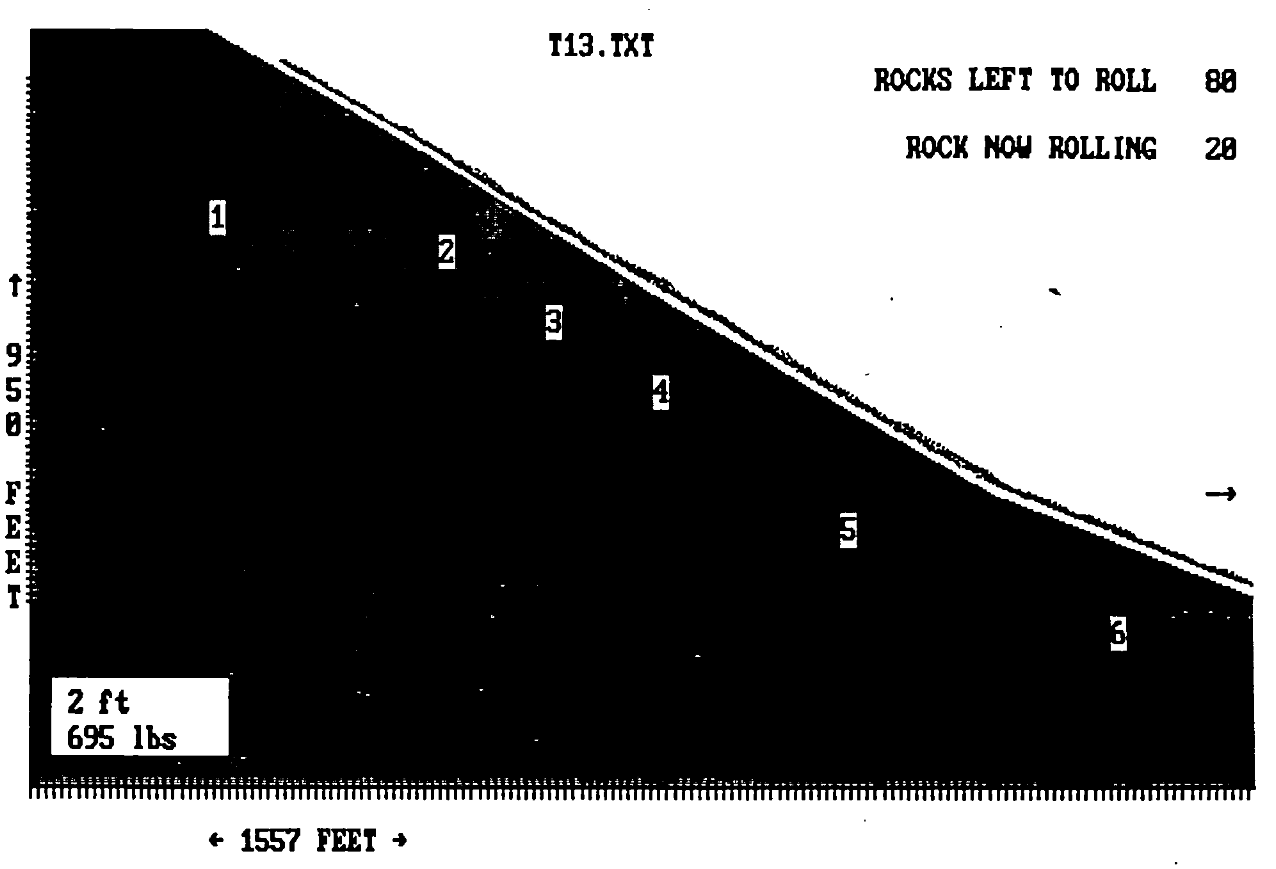
T6B.TXT
ROCKS LEFT TO ROLL 92
ROCK NOW ROLLING 8
2658 FEET
3 ft
2947 lbs
10
11
12
← 4459 FEET →


T10.TXT
ROCKS LEFT TO ROLL 94
ROCK NOW ROLLING 6
1
2
3
4
5
↑ 2030 FEET
3 ft
2347 lbs
↓
← 2658 FEET →
6


T11.TXT
ROCKS LEFT TO ROLL 89
ROCK NOW ROLLING 11
1
2
3
4
5
↑ 1128 FEET
→
3 ft
2347 lbs
← 1755 FEET →
6



T12.TXT
ROCKS LEFT TO ROLL 52
ROCK NOW ROLLING 48
1
2
3
4
5
↑
555 FEET
2 ft
695 lbs
← 960 FEET →


T13.TXT
ROCKS LEFT TO ROLL 80
ROCK NOW ROLLING 20
1
2
3
4
5
6
950 FEET
2 ft
695 lbs
← 1557 FEET →

ICICLE CANYON SITES

R1A.TXT

This file is a compilation of the south transect of Area R-1, cells 1-4, and a profile developed from a 1:25,000 topographic map, cells 5-10.

2 ft. rocks...none past cell 10
3 ft. rocks...none past cell 10
4 ft. rocks...7 past cell 10 out of 100 rolled

R2A.TXT

R2A has the analysis point at mid-debris fan..One home at this location
Rt reduced to 0.2 in cells 11-13 due to heavily timbered zone on section
2 ft. rocks...none past analysis point
3 ft. rocks...none past analysis point
4 ft. rocks...52 out of 100 pass analysis point
6 ft. rocks...96 out of 100 pass analysis point

R2B.TXT

Same profile as R2A, but the analysis point is at road..5 homes at this location
Rt reduced to 0.2 in cells 11-13 due to heavily timbered zone on section
4 ft. rocks...none pass analysis point
6 ft. rocks...none pass analysis point

R3A.TXT

Analysis point at road..3 homes..trailer park..
Changed some S and Rt values from field notes
2 ft. rocks..none made it to analysis point
3 ft rocks..none made it to analysis point
6 ft. rocks...none made it to analysis point

R4A.TXT

This file simulates the conditions in Areas R4, and R5. Initiation in Cell #3..adjacent to loose rocks and outcrops.
Analysis point is at water filtration plant..
Increased S values
Rt is closer to 0.5 due to tree density
2 ft. rocks...none made it to the road..50 rolled
3 ft. rocks...2 rocks made it to the road..50 rolled

R4B.TXT

Same profile and conditions of R4A, but analysis point is at road.

2 ft. rocks...none make it to road
3 ft. rocks..9 make it to road
4 ft. rocks..99 make it to road

R5

See R4.txt

R6

Not modeled..Area determined to be no to low risk of rockfall based on ground observations

R7

Low potential for rockfall..not modeled

R8/8B

Upslope of R7..low potential..not modeled

R9

Common pathway with R-7..not modeled

R10.TXT

Analysis point at road with two homes
2 ft. rocks...none pass analysis point out of 100
3 ft. rocks...1 passes analysis point out of 100

R11A/11B

Common pathway with R2..use R2 analysis.

R12.TXT

Analysis point at road
3 ft. rocks...12 pass analysis point out of 100

R13.TXT

Analysis point at road

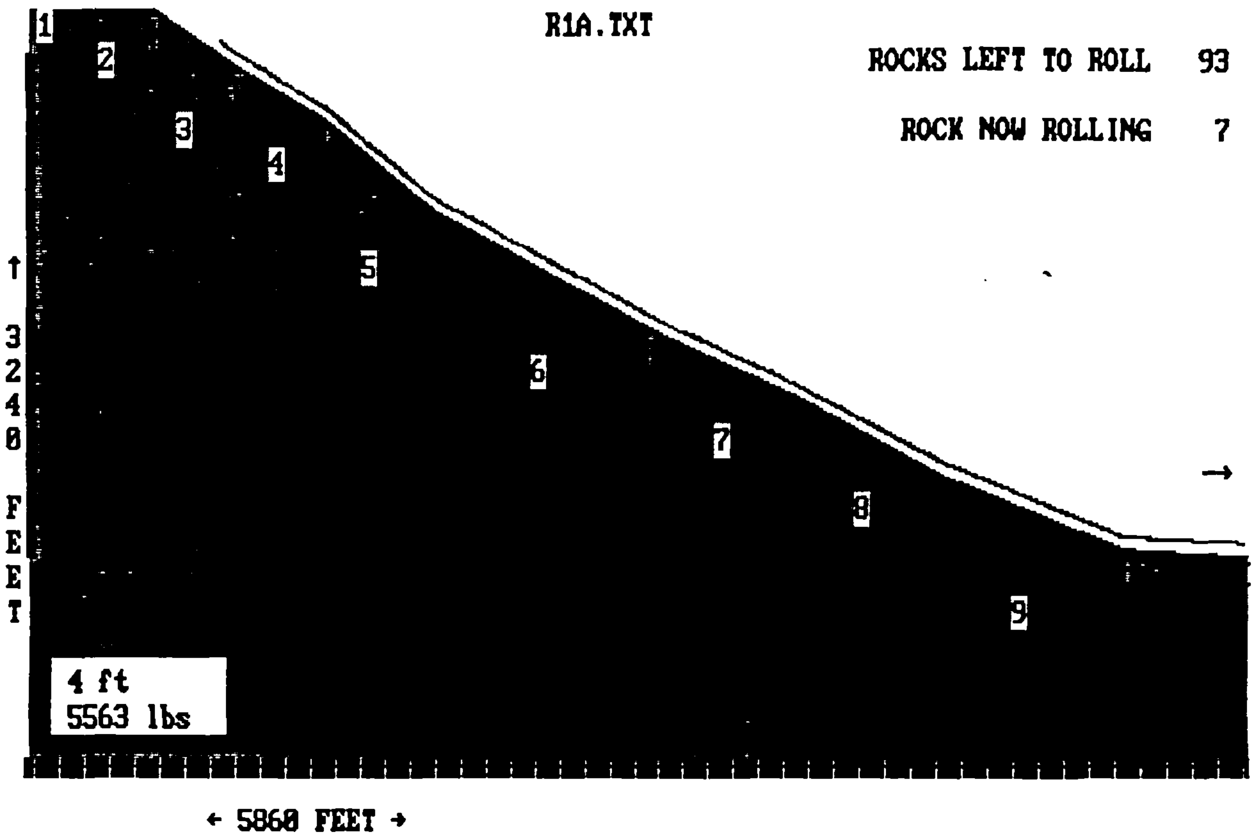
2 ft. rocks..none make it to road
3 ft. rocks..2 make it to road out of 100 simulated

W1.TXT

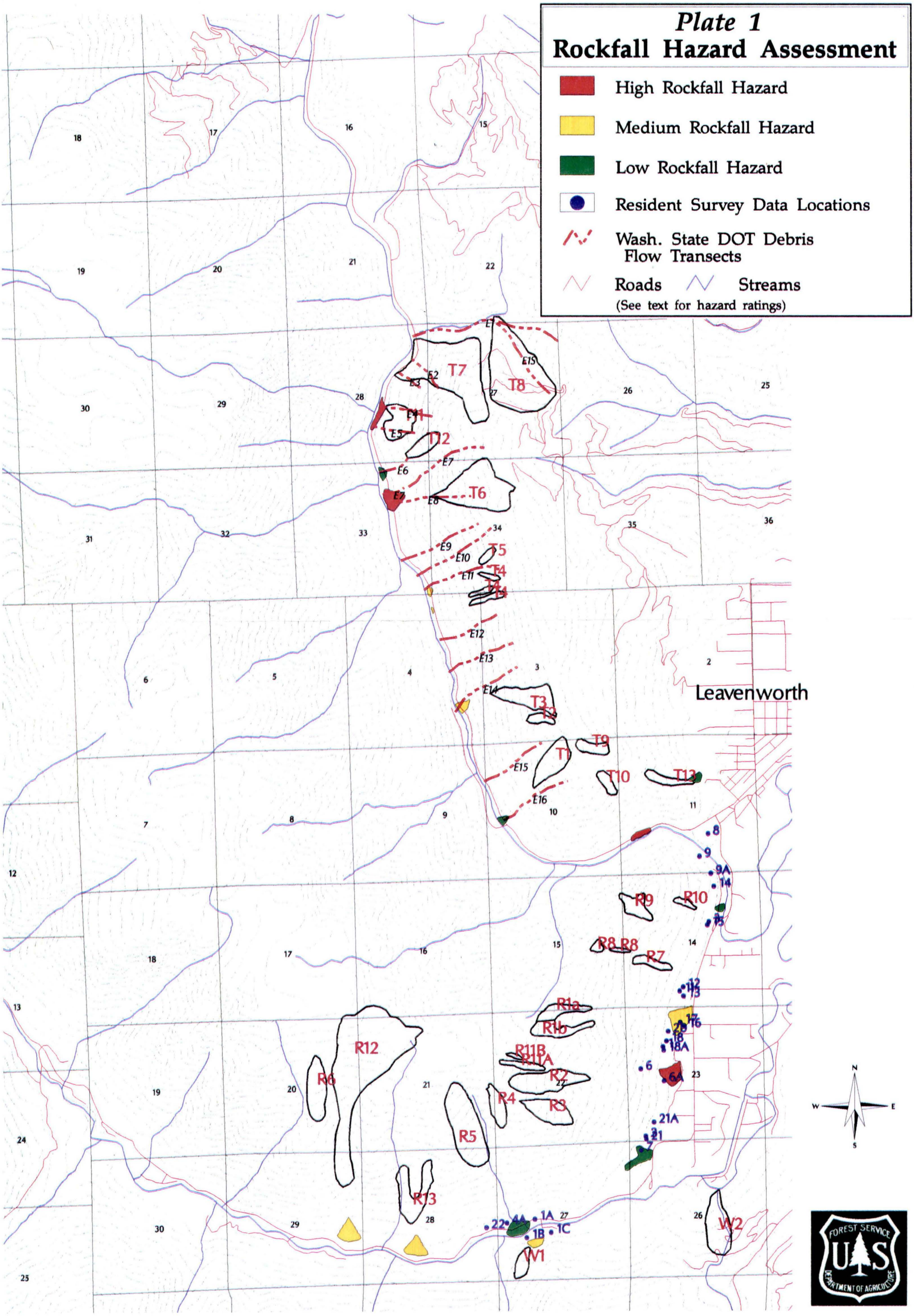
Initiation in cell #2..analysis point at irrigation canal
2 ft. rocks...none past analysis point
3 ft. rocks...3 past analysis point
4 ft. rocks...48 past analysis analysis point

W2

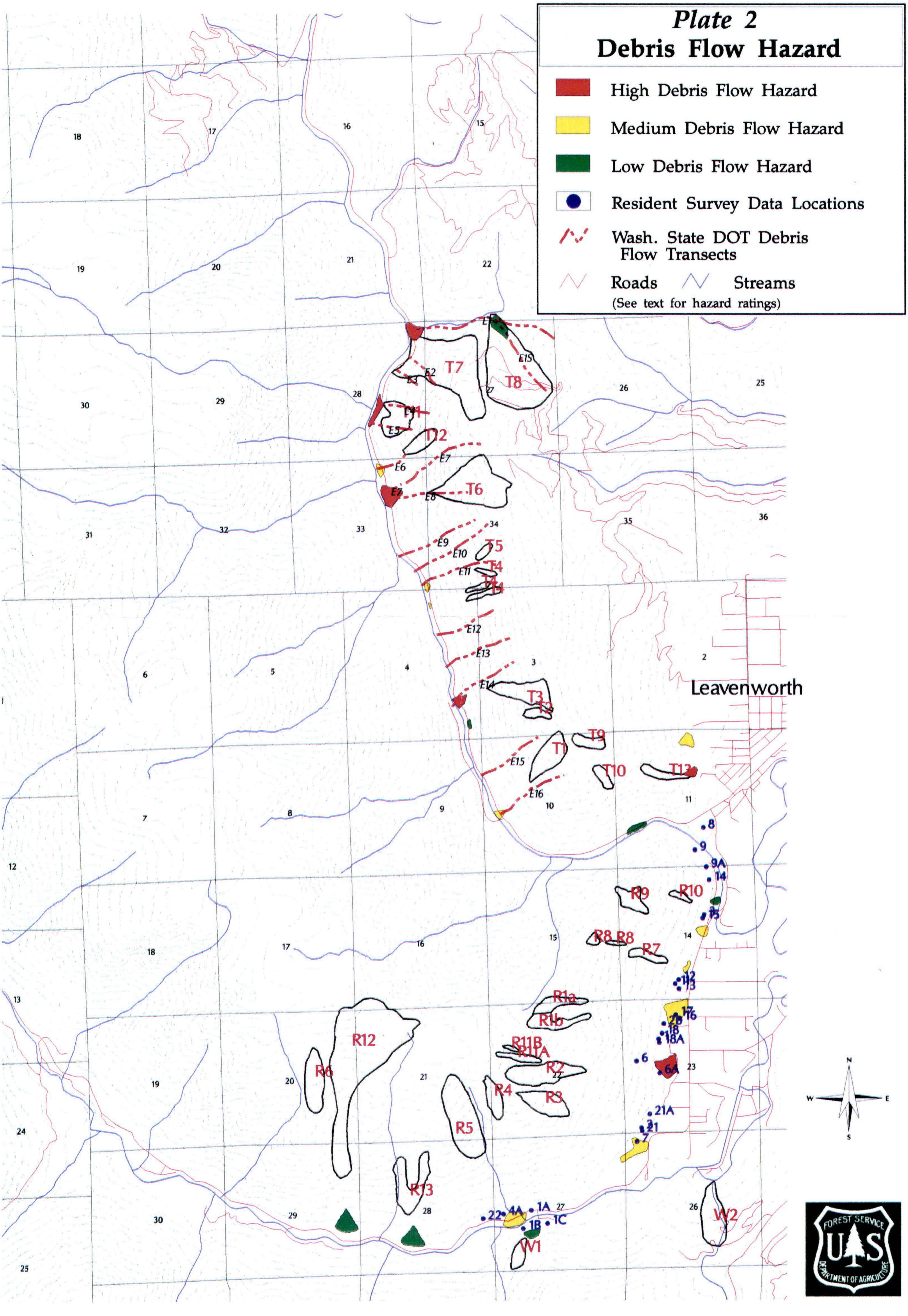
Not modeled..observations and low slope angles....area determined to be low rockfall hazard..


R1A.TXT
ROCKS LEFT TO ROLL 93
ROCK NOW ROLLING 7
1
2
3
4
5
6
7
8
9
3240 FEET
4 ft
5563 lbs
← 5860 FEET →

Wenatchee National Forest



Wenatchee National Forest



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